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HEATS, EQUILIBRIUM CONSTANTS, AND FREE ENERGIES OF FORMATION OF THE MONOOLEFIN HYDROCARBONS¹

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ABSTRACT

For ethylene, propylene, each of the four butenes, six pentenes, and 17 hexenes, and for the higher normal 1-alkenes, values are presented for the following thermodynamic properties to 1,000° or 1,500°K: The heat of formation from the elements, ΔH_f° ; the free energy of formation from the elements, ΔF_f° ; and the logarithm of the equilibrium constant of formation from the elements, $\log_{10} K_f$. For each of the 6 pentenes and 17 hexenes, values are also given to 1,000° or 1,500°K, for the following properties: The heat-content function, $(H^\circ - H_0^\circ)/T$; the free-energy function, $(F^\circ - H_0^\circ)/T$; the entropy, S° ; the heat content, $H^\circ - H_0^\circ$; and the heat capacity, C_p° .

Equilibrium constants and concentrations are given in tabular and graphical form for the isomerization of the 4 butenes, 6 pentenes, and 17 hexenes, as a function of the temperature to 1,000° or 1,500°K. Equilibrium constants are also given in tabular and graphical form for some reactions of hydrogenation, dimerization, and alkylation.

CONTENTS

	Page
I. Introduction.....	560
II. Units and constants.....	560
III. Heat-content function, free-energy function, entropy, heat content, and heat capacity.....	560
1. Method and data used in the calculations.....	560
(a) Ethylene, propylene, and the four butenes.....	560
(b) Pentenes and hexenes.....	560
2. Results for the pentenes and hexenes.....	563
IV. Heat of formation, free energy of formation, and equilibrium constant of formation.....	563
1. Method and data used in the calculations.....	563
2. Results for all the monoolefins through the hexenes and for the higher normal 1-alkenes.....	564
V. Free energies and equilibria of isomerization of the butenes, pentenes, and hexenes.....	591
VI. Equilibrium constants for some reactions involving hydrogenation, dimerization, and alkylation.....	603
VII. References.....	612

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I. INTRODUCTION

As part of the work of the American Petroleum Institute Research Project 44 and the Thermochemical Laboratory at the National Bureau of Standards, values have been calculated for the heat-content function, the free-energy function, entropy, heat content, and heat capacity, of the 6 pentenes and 17 hexenes in the gaseous state to 1,000° or 1,500° K, and for the higher normal 1-alkenes in the gaseous state to 1,500° K. These data have been combined with similar values calculated for ethylene, propylene, and four butenes, all in the gaseous state, to 1,500° K [1],⁴ and with the previously reported values of the heats of formation at 25° C, from the elements, of all the monoolefin hydrocarbons through the hexenes and of the higher normal 1-alkenes [2], to obtain, for the corresponding temperatures to 1,000° or 1,500° K, values of the heats, free energies, and equilibrium constants of formation of the 29 monoolefin hydrocarbons through the hexenes and of the higher normal 1-alkenes, values of the free energies and equilibrium constants of isomerization of the butenes, pentenes, and hexenes, and values of the equilibrium constants for some reactions involving hydrogenation, dimerization, and alkylation. The results are presented in this report in tabular and graphical form.

II. UNITS AND CONSTANTS

The unit of energy, atomic weights, and values of the fundamental constants used in this report are the same as those previously described [3].

III. HEAT-CONTENT FUNCTION, FREE-ENERGY FUNCTION, ENTROPY, HEAT CONTENT, AND HEAT CAPACITY

1. METHOD AND DATA USED IN THE CALCULATIONS

Details of the statistical calculations not described here may be found in references [1, 3, 4].

(a) ETHYLENE, PROPYLENE, AND THE FOUR BUTENES

The values for these six monoolefins are taken directly from reference [1].

(b) PENTENES AND HEXENES

As no appropriate calorimetric data nor complete spectroscopic data for the pentenes were available, an approximate method of calculation was used for these molecules, similar to the method used for the pentynes [4]. This method involves the addition to the values for 1-butene (modified as described below) of contributions arising from appropriate structural increments determined from the lower members of the paraffin and monoolefin series, with cognizance being taken, where necessary, of differences in the symmetry numbers and in the potential barriers restricting internal rotation.

The only potential barriers restricting internal rotation that require special consideration in this report are those involving the rota-

⁴ Figures in brackets indicate the references at the end of this paper.

tion of an ethyl or larger alkyl group that is attached to a doubly bonded atom. All other barriers restricting internal rotation were taken to be the same as in the corresponding paraffin or lower olefin hydrocarbons. The barriers restricting internal rotation of an ethyl, *n*-propyl, or isopropyl group attached to a doubly bonded carbon in the pentenes were taken as indicated in figure 1 and table 1. In figure 1, the several barriers are given by the following relations:

Type (a):

$$V = (1/2)(1 - \sin 3\phi)2400 \text{ cal/mole}; 0^\circ < \phi < 240^\circ \\ = 2400 \text{ cal/mole}; 240^\circ < \phi < 360^\circ \quad (1)$$

Type (b):

$$V = (1/2)(1 - \sin 3\phi)2400 \text{ cal/mole}; 0^\circ < \phi < 240^\circ \\ = \infty \text{ cal/mole}; 240^\circ < \phi < 360^\circ \quad (2)$$

Type (c):

$$V = (1/2)(1 - \sin 3\phi)2400 \text{ cal/mole}; 0^\circ < \phi < 120^\circ \\ = 2400 \text{ cal/mole}; 120^\circ < \phi < 360^\circ \quad (3)$$

Type (d):

$$V = (1/2)(1 - \sin 3\phi)2400 \text{ cal/mole}; 0^\circ < \phi < 360^\circ \quad (4)$$

A potential barrier of type (a) was used in the case of 1-butene [1]. The equations of tables 1 and 2 for the pentene and hexene isomers in which the skeletal rotation adjacent to the ethylenic group is essentially the same as in 1-butene do not mention potential barrier type (a) explicitly, as the effect of this hindering potential is included in the functions of 1-butene.

For calculating the contribution to a given thermodynamic property arising from the restricted rotation in the foregoing cases, the classical partition function may be used, since the moment of inertia of the rotating group (ethyl or propyl) is considerably larger than that of the methyl group:

$$Q = \left[(2\pi I k T)^{1/2} / n h \right] \int_0^{2\pi} e^{-V/RT} d\phi, \quad (5)$$

where

- Q = the classical partition function for internal rotation
- I = the reduced moment of inertia of the rotating group
- k = the Boltzmann constant
- T = the absolute temperature
- n = the symmetry number for the given rotation
- h = Planck's constant
- V = the potential energy of the rotor, a function of ϕ
- R = the gas constant
- ϕ = the angle of rotation.

The integral in eq 5 was readily evaluated for each case in terms of Bessel functions.

The equations for calculating the thermodynamic functions of pentenes and hexenes are given in tables 1 and 2.

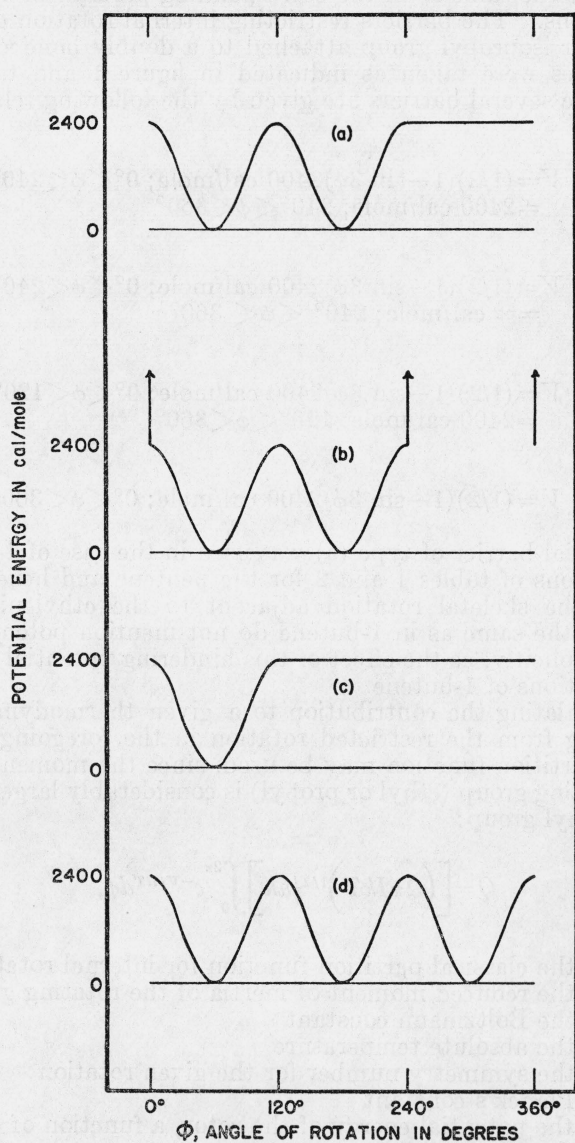


FIGURE 1.—Potential barriers restricting internal rotation.

See text for explanation.

TABLE 1.—Components used in the evaluation of the heat-content function, $(H^\circ - H_0^\circ)/T$, the entropy, S° , the negative of the free-energy function, $-(F^\circ - H_0^\circ)/T$, and the heat capacity, C_p° , for the pentenes

No.	Compound	Components ^a
1	1-Pentene.....	1-Butene+(<i>n</i> -butane-propane).
2	<i>cis</i> -2-Pentene.....	1-Butene*+(type b internal rotation for the ethyl group)+(cis-2-butene-propylene)+ <i>Rln</i> 2.
3	<i>trans</i> -2-Pentene.....	1-Butene+(<i>trans</i> -2-butene-propylene)+ <i>Rln</i> 2.
4	2-Methyl-1-butene.....	1-Butene*+(type c internal rotation for the ethyl group)+(isobutane-propylene)+ <i>Rln</i> 2.
5	3-Methyl-1-butene.....	1-Butene*+(type d, internal rotation for the isopropyl group)+(isobutane-propane)+ <i>Rln</i> (3/2).
6	2-Methyl-2-butene.....	2/3 (cis-2-Butene+ <i>trans</i> -2-butene+isobutene)−(propylene)+ <i>Rln</i> 4.

^a See figure 1 and the text for the description of the potential barriers restricting internal rotation. The term involving *Rln* is to be included for the entropy and the negative of the free-energy function but disregarded for the heat-content function and the heat capacity. The asterisk on 1-butene indicates the value not including the contribution arising from the internal rotation of the ethyl group in 1-butene. For *cis*-2-pentene, the particular set of components chose results in a much smaller net restriction on the internal rotation of the ethyl group than is apparent at first glance.

TABLE 2.—Components used in the evaluation of the heat-content function $(H^\circ - H_0^\circ)/T$, the entropy, S° , the negative of the free-energy function, $-(F^\circ - H_0^\circ)/T$, and the heat capacity, C_p° , for the hexenes

No.	Compound	Components ^a
1	1-Hexene.....	1-Butene+(<i>n</i> -pentene-propane).
2	<i>cis</i> -2-Hexene.....	<i>cis</i> -2-Pentene+(<i>n</i> -butane-propane).
3	<i>trans</i> -2-Hexene.....	<i>trans</i> -2-Pentene+(<i>n</i> -butane-propane).
4	<i>cis</i> -3-Hexene.....	<i>cis</i> -2-Pentene+(<i>cis</i> -2-pentene- <i>cis</i> -2-butene)− <i>Rln</i> 4.
5	<i>trans</i> -3-Hexene.....	<i>trans</i> -2-Pentene+(<i>trans</i> -2-pentene- <i>trans</i> -2-butene)− <i>Rln</i> 4.
6	2-Methyl-1-pentene.....	2-Methyl-1-butene+(<i>n</i> -butane-propane).
7	3-Methyl-1-pentene.....	3-Methyl-1-butene+(2-methylbutane-isobutene)− <i>Rln</i> (3/2).
8	4-Methyl-1-pentene.....	1-Pentene+(2-methylbutane- <i>n</i> -butane)− <i>Rln</i> 2.
9	2-Methyl-2-pentene.....	<i>cis</i> -2-Pentene+(isobutene-propylene)+ <i>Rln</i> 2.
10	<i>cis</i> -3-Methyl-2-pentene.....	<i>cis</i> -2-Pentene+(isobutene-propylene)+ <i>Rln</i> 2.
11	<i>trans</i> -3-Methyl-2-pentene.....	2-Methyl-1-butene+(<i>cis</i> -2-butene-propylene)+ <i>Rln</i> 2.
12	<i>cis</i> -4-Methyl-2-pentene.....	3-Methyl-1-butene+(<i>cis</i> -2-butene-propylene)+ <i>Rln</i> 2.
13	<i>trans</i> -4-Methyl-2-pentene.....	3-Methyl-1-butene+(<i>trans</i> -2-butene-propylene)+ <i>Rln</i> 2.
14	2-Ethyl-1-butene.....	2-Methyl-1-butene+(2-methyl-1-butene-isobutene)− <i>Rln</i> (36/7).
15	2,3-Dimethyl-1-butene.....	3-Methyl-1-butene+(isobutene-propylene)+ <i>Rln</i> 2.
16	3,3-Dimethyl-1-butene.....	Propylene+(2,2-dimethylbutane-propane)− <i>Rln</i> 2.
17	2,3-Dimethyl-2-butene.....	<i>cis</i> -2-Butene+isobutene+ <i>trans</i> -2-butene−2(propylene)+ <i>Rln</i> 2.

^a The term involving *Rln* is to be included for the entropy and the negative of the free-energy function but disregarded for the heat-content function and the heat capacity.

2. RESULTS FOR THE PENTENES AND HEXENES

The resulting values of thermodynamic properties for the 6 pentenes, 17 hexenes, and the higher normal 1-alkenes are presented in tables 3 to 17, which give values of the heat-content function, $(H^\circ - H_0^\circ)/T$; the free-energy function, $(F^\circ - H_0^\circ)/T$; the entropy, S° ; the heat content, $H^\circ - H_0^\circ$; and the heat capacity, C_p° .

IV. HEAT OF FORMATION, FREE ENERGY OF FORMATION, AND EQUILIBRIUM CONSTANT OF FORMATION

1. METHOD AND DATA USED IN THE CALCULATIONS

The same method of calculation was used as described in Section IV-1 of reference [3].

For the heats of formation at 25° C of the monoolefin hydrocarbons in the gaseous state from the elements, solid carbon (graphite) and gaseous hydrogen, the values given in reference [2] were used.

2. RESULTS FOR ALL THE MONOOLEFINS THROUGH THE HEXENES AND FOR THE HIGHER NORMAL 1-ALKENES

The resulting values of the thermodynamic properties for the formation of ethylene, propylene, 4 butenes, 6 pentenes, 17 hexenes, and the higher normal 1-alkenes, in the gaseous state, from the elements carbon (solid, graphite) and hydrogen (gaseous), are presented in tables 18 to 29, which give values of the heat of formation, ΔH_f° ; the free energy of formation, ΔF_f° ; and the logarithm of the equilibrium constant of formation, $\log_{10} K_f$; all to 1,000° or 1,500° K.

Figure 2 shows the thermodynamic stability of the normal 1-alkenes in the gaseous state as a function of temperature, in the form of a plot of the standard free energy of formation, per carbon atom, divided by the absolute temperature. This plot may be compared with corresponding plots for the normal paraffins and the 1-alkynes [4, 5].

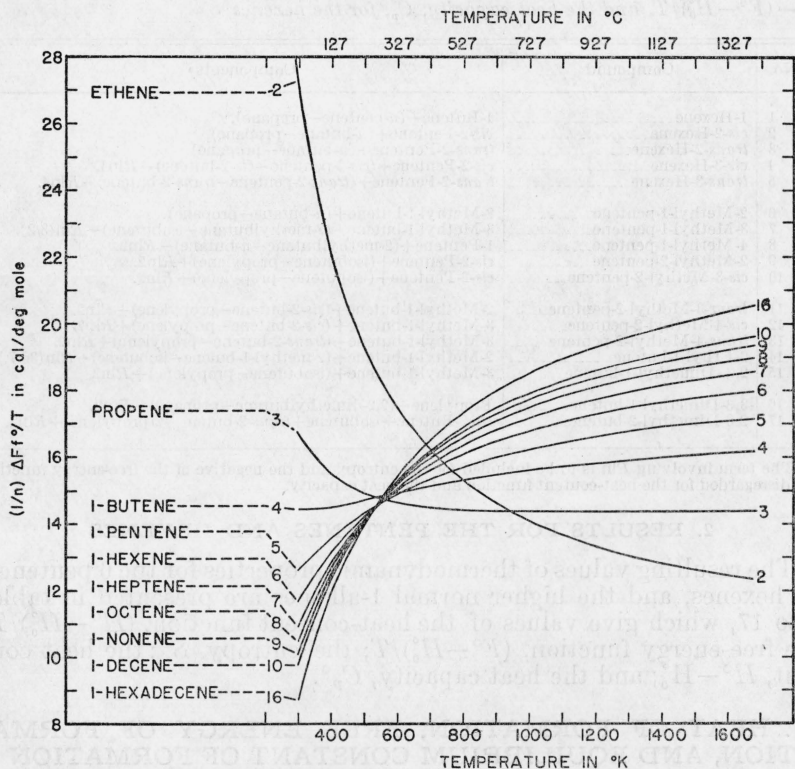


FIGURE 2.—Thermodynamic stability of the 1-alkene hydrocarbons in the gaseous state as a function of temperature.

The scale of ordinates gives the value of $(1/n) (\Delta F_f^\circ / T)$ in calories per degree mole, where n is the number of carbon atoms per molecule, T is the absolute temperature in degrees Kelvin, and ΔF_f° is the standard free energy of formation of the hydrocarbon from the elements, solid carbon (graphite) and gaseous hydrogen, as given in table 10. The scale of abscissas gives the temperature in degrees Kelvin.

TABLE 3.—Values^a of the heat content function, $(H^\circ - H_0^\circ)/T$, for the six pentenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in °K							
		0	298.16	300	400	500	600	700	800
		Heat-content function, ^b $(H^\circ - H_0^\circ)/T$, in cal/deg mole							
1-Pentene.....	C ₅ H ₁₀	0	17.97	18.02	21.25	24.45	27.53	30.40	33.05
cis-2-Pentene.....	C ₅ H ₁₀	0	16.25	16.29	19.24	22.38	25.47	28.41	31.14
trans-2-Pentene.....	C ₅ H ₁₀	0	17.27	17.32	20.54	23.76	26.85	29.71	32.39
2-Methyl-1-butene.....	C ₅ H ₁₀	0	16.77	16.82	20.20	23.53	26.69	29.63	32.34
3-Methyl-1-butene.....	C ₅ H ₁₀	0	17.23	17.29	20.95	24.42	27.61	30.53	33.20
2-Methyl-2-butene.....	C ₅ H ₁₀	0	16.38	16.43	19.55	22.70	25.77	28.66	31.37

Compound (gas)	Formula	Temperature ^a in °K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Heat-content function, ^b $(H^\circ - H_0^\circ)/T$, in cal/deg mole						
1-Pentene.....	C ₅ H ₁₀	35.48	37.74	39.84	41.78	43.59	45.26	46.81
cis-2-Pentene.....	C ₅ H ₁₀	33.68	36.05	38.22	40.24	42.12	43.86	45.48
trans-2-Pentene.....	C ₅ H ₁₀	34.86	37.16	39.28	41.24	43.06	44.75	46.33
2-Methyl-1-butene.....	C ₅ H ₁₀	34.83	37.15	39.30	41.27	43.11	44.82	46.39
3-Methyl-1-butene.....	C ₅ H ₁₀	35.66	37.94	40.04	41.99	43.79	45.44	46.97
2-Methyl-2-butene.....	C ₅ H ₁₀	33.87	36.20	38.36	40.37	42.23	43.96	45.57

^a Interpolation to other temperatures in the interval 298.16° to 1,500° K may be made by appropriate graphical or analytical methods. For temperatures between 200° and 298.16° K, values may be estimated by extrapolating the values for 300°, 400°, 500° and 600° K. The values in this table are given to more significant figures than are warranted by the absolute accuracy of the individual values in order to retain the internal consistency of the several thermodynamic functions of a single substance, and also to retain the significance of the increment with temperature of a given thermodynamic function.

^b The heat-content function, $(H^\circ - H_0^\circ)/T$, is the heat content at the given temperature less the heat content at 0°K, divided by the absolute temperature (°K) of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere).

TABLE 4.—Values ^a of the heat-content function, $(H^\circ - H_0^\circ)/T$, for the 17 hexenes, for the ideal gaseous state, to 1,500°K

Compound (gas)	For- mula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Heat-content function ^b , ($H^\circ - H_0^\circ$)/T, in cal/deg mole							
1-Hexene.....	C ₆ H ₁₂	0	21.40	21.46	25.5	29.4	33.1	36.6	39.8
cis-2-Hexene.....	C ₆ H ₁₂	0	20.05	20.11	23.8	27.6	31.3	34.8	38.1
trans-2-Hexene.....	C ₆ H ₁₂	0	21.07	21.13	25.1	29.0	32.7	36.2	39.4
cis-3-Hexene.....	C ₆ H ₁₂	0	19.29	19.36	23.1	27.0	30.8	34.4	37.7
trans-3-Hexene.....	C ₆ H ₁₂	0	20.51	20.57	24.7	28.7	32.5	36.1	39.3
2-Methyl-1-pentene.....	C ₆ H ₁₂	0	20.57	20.63	24.7	28.7	32.5	36.1	39.3
3-Methyl-1-pentene.....	C ₆ H ₁₂	0	20.13	20.21	24.8	29.1	33.0	36.6	39.9
4-Methyl-1-pentene.....	C ₆ H ₁₂	0	19.63	19.70	24.1	28.3	32.3	36.0	39.3
2-Methyl-2-pentene.....	C ₆ H ₁₂	0	19.05	19.11	23.0	27.0	30.8	34.4	37.8
cis-3-Methyl-2-pentene.....	C ₆ H ₁₂	0	19.05	19.11	23.0	27.0	30.8	34.4	37.8
trans-3-Methyl-2-pentene.....	C ₆ H ₁₂	0	19.05	19.11	23.0	27.0	30.8	34.4	37.8
cis-4-Methyl-2-pentene.....	C ₆ H ₁₂	0	19.51	19.58	23.8	27.9	31.8	35.3	38.6
trans-4-Methyl-2-pentene.....	C ₆ H ₁₂	0	20.33	20.40	24.8	28.9	32.8	36.3	39.5
2-Ethyl-1-butene.....	C ₆ H ₁₂	0	19.81	19.87	24.0	28.1	32.0	35.6	38.9
2,3-Dimethyl-1-butene.....	C ₆ H ₁₂	0	20.03	20.10	24.7	29.0	33.0	36.6	39.8
3,3-Dimethyl-1-butene.....	C ₆ H ₁₂	0	18.71	18.75	23.2	27.6	31.7	35.6	39.1
2,3-Dimethyl-2-butene.....	C ₆ H ₁₂	0	19.11	19.16	23.0	26.9	30.7	34.2	37.5

Compound (gas)	For- mula	Temperature ^a in ° K							
		900	1,000	1,100	1,200	1,300	1,400	1,500	
		Heat-content function, ^b ($H^\circ - H_0^\circ$)/T, in cal/deg mole							
1-Hexene.....	C ₆ H ₁₂	42.8	45.5	48.0	50.4	52.6	54.6	56.5	
cis-2-Hexene.....	C ₆ H ₁₂	41.1	44.0	---	---	---	---	---	
trans-2-Hexene.....	C ₆ H ₁₂	42.3	45.1	---	---	---	---	---	
cis-3-Hexene.....	C ₆ H ₁₂	40.8	43.7	---	---	---	---	---	
trans-3-Hexene.....	C ₆ H ₁₂	42.3	45.1	---	---	---	---	---	
2-Methyl-1-pentene.....	C ₆ H ₁₂	42.3	45.1	---	---	---	---	---	
3-Methyl-1-pentene.....	C ₆ H ₁₂	42.9	45.7	---	---	---	---	---	
4-Methyl-1-pentene.....	C ₆ H ₁₂	42.4	45.2	---	---	---	---	---	
2-Methyl-2-pentene.....	C ₆ H ₁₂	40.8	43.7	---	---	---	---	---	
cis-3-Methyl-2-pentene.....	C ₆ H ₁₂	40.8	43.7	---	---	---	---	---	
trans-3-Methyl-2-pentene.....	C ₆ H ₁₂	40.8	43.7	---	---	---	---	---	
cis-4-TransMethyl-2-pentene.....	C ₆ H ₁₂	41.6	44.5	---	---	---	---	---	
trans-4-Methyl-2-pentene.....	C ₆ H ₁₂	42.5	45.3	---	---	---	---	---	
2-Ethyl-1-butene.....	C ₆ H ₁₂	42.0	44.8	---	---	---	---	---	
2,3-Dimethyl-1-butene.....	C ₆ H ₁₂	42.8	45.6	---	---	---	---	---	
3,3-Dimethyl-1-butene.....	C ₆ H ₁₂	42.2	45.1	---	---	---	---	---	
2,3-Dimethyl-2-butene.....	C ₆ H ₁₂	40.5	43.4	---	---	---	---	---	

^a See footnote "a" of table 3.^b The heat-content function, $(H^\circ - H_0^\circ)/T$, is the heat content at the given temperature less the heat content at 0°K, divided by the absolute temperature (°K) of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere).

TABLE 5.—Values ^a of the heat-content function $(H^\circ - H_0^\circ)/T$, for the higher 1-alkenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in °K							
		0	298.16	300	400	500	600	700	800
		Heat-content function ^b $(H^\circ - H_0^\circ)/T$ in cal/deg mole							
1-Heptene.....	C ₇ H ₁₄	0	24.83	24.91	29.7	34.3	38.7	42.8	46.6
1-Octene.....	C ₈ H ₁₆	0	28.26	28.36	33.9	39.2	44.3	49.0	53.4
1-Nonene.....	C ₉ H ₁₈	0	31.69	31.80	38.1	44.1	49.9	55.2	60.1
1-Decene.....	C ₁₀ H ₂₀	0	35.12	35.25	42.3	49.0	55.5	61.5	66.9
1-Undecene.....	C ₁₁ H ₂₂	0	38.55	38.69	46.5	53.9	61.0	67.7	73.7
1-Dodecene.....	C ₁₂ H ₂₄	0	41.98	42.14	50.7	58.9	66.6	73.9	80.5
1-Tridecene.....	C ₁₃ H ₂₆	0	45.41	45.58	54.9	63.8	72.2	80.1	87.2
1-Tetradecene.....	C ₁₄ H ₂₈	0	48.84	49.03	59.1	68.7	77.8	86.3	94.0
1-Pentadecene.....	C ₁₅ H ₃₀	0	52.27	52.47	63.3	73.6	83.4	92.5	100.8
1-Hexadecene.....	C ₁₆ H ₃₂	0	55.70	55.92	67.6	78.5	89.0	98.7	107.6
1-Heptadecene.....	C ₁₇ H ₃₄	0	59.13	59.36	71.8	83.4	94.6	105.0	114.3
1-Octadecene.....	C ₁₈ H ₃₆	0	62.56	62.81	76.0	88.4	100.1	111.2	121.1
1-Nonadecene.....	C ₁₉ H ₃₈	0	65.99	66.25	80.2	93.3	105.7	117.4	127.9
1-Eicosene.....	C ₂₀ H ₄₀	0	69.42	69.70	84.4	98.2	111.3	123.6	134.7
Δ per CH ₂	---	0	3.430	3.445	4.21	4.92	5.59	6.22	6.78

Compound (gas)	Formula	Temperature ^a in °K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Heat-content function ^b $(H^\circ - H_0^\circ)/T$ in cal/deg mole						
1-Heptene.....	C ₇ H ₁₄	50.0	53.3	56.3	59.0	61.6	63.9	66.1
1-Octene.....	C ₈ H ₁₆	57.3	61.1	64.5	67.6	70.6	73.3	75.8
1-Nonene.....	C ₉ H ₁₈	64.6	68.8	72.7	76.3	79.6	82.6	85.5
1-Decene.....	C ₁₀ H ₂₀	71.9	76.6	80.9	84.9	88.6	92.0	95.1
1-Undecene.....	C ₁₁ H ₂₂	79.2	84.4	89.1	93.5	97.6	101.3	104.8
1-Dodecene.....	C ₁₂ H ₂₄	86.5	92.2	97.4	102.1	106.6	110.7	114.4
1-Tridecene.....	C ₁₃ H ₂₆	93.8	100.0	105.6	110.7	115.6	120.0	124.1
1-Tetradecene.....	C ₁₄ H ₂₈	101.1	107.7	113.8	119.4	124.6	129.4	133.8
1-Pentadecene.....	C ₁₅ H ₃₀	108.4	115.5	122.0	128.0	133.6	138.7	143.4
1-Hexadecene.....	C ₁₆ H ₃₂	115.7	123.3	130.2	136.6	142.6	148.1	153.1
1-Heptadecene.....	C ₁₇ H ₃₄	123.0	131.1	138.5	145.2	151.6	157.4	162.7
1-Octadecene.....	C ₁₈ H ₃₆	130.3	138.9	146.7	153.8	160.6	166.8	172.4
1-Nonadecene.....	C ₁₉ H ₃₈	137.6	146.6	154.9	162.5	169.6	176.1	182.1
1-Eicosene.....	C ₂₀ H ₄₀	144.9	154.4	163.1	171.1	178.6	185.5	191.7
Δ per CH ₂	---	7.30	7.78	8.22	8.62	9.00	9.35	9.66

^a See footnote "a" of table 3.^b The heat-content function $(H^\circ - H_0^\circ)/T$, is the heat content at the given temperature less the heat content at 0° K, divided by the absolute temperature (°K) of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere).

TABLE 6.—Values ^a of the free energy function, $(F^\circ - H_0^\circ)/T$, for the six pentenes, for the ideal gaseous state, to 1500° K

Compound (gas)	Formula	Temperature ^a in °K							
		0	298.16	300	400	500	600	700	800
		Free-energy function ^b , $(F^\circ - H_0^\circ)/T$, in cal/deg mole							
1-Pentene.....	C ₅ H ₁₀	0	-65.11	-65.23	-70.88	-75.96	-80.68	-85.13	-89.37
cis-2-Pentene.....	C ₅ H ₁₀	0	-66.51	-66.60	-71.73	-76.30	-80.64	-84.80	-88.76
trans-2-Pentene.....	C ₅ H ₁₀	0	-64.54	-64.65	-70.13	-75.01	-79.60	-83.97	-88.12
2-Methyl-1-butene.....	C ₅ H ₁₀	0	-64.96	-65.06	-70.41	-75.23	-79.80	-84.14	-88.27
3-Methyl-1-butene.....	C ₅ H ₁₀	0	-62.47	-62.57	-67.99	-73.12	-77.87	-82.34	-86.59
2-Methyl-2-butene.....	C ₅ H ₁₀	0	-64.52	-64.63	-69.84	-74.48	-78.88	-83.09	-87.09

Compound (gas)	Formula	Temperature ^a in °K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Free-energy function ^b , $(F^\circ - H_0^\circ)/T$, in cal/deg mole						
1-Pentene.....	C ₅ H ₁₀	-93.42	-97.29	-100.98	-104.52	-107.91	-111.20	-114.39
cis-2-Pentene.....	C ₅ H ₁₀	-92.59	-96.27	-99.82	-103.22	-106.52	-109.70	-112.81
trans-2-Pentene.....	C ₅ H ₁₀	-92.07	-95.87	-99.51	-103.02	-106.39	-109.64	-112.78
2-Methyl-1-butene.....	C ₅ H ₁₀	-92.24	-96.04	-99.69	-103.18	-106.55	-109.80	-112.96
3-Methyl-1-butene.....	C ₅ H ₁₀	-90.65	-94.51	-98.23	-101.77	-105.20	-108.51	-111.73
2-Methyl-2-butene.....	C ₅ H ₁₀	-90.93	-94.62	-98.18	-101.60	-104.91	-108.09	-111.19

^a See footnote "a" of table 3.^b The free-energy function, $(F^\circ - H_0^\circ)/T$, is the free energy at the given temperature less the heat content at 0°K, divided by the absolute temperature (°K), of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere).

TABLE 7.—Values ^a of the free-energy function, $(F^\circ - H_0^\circ)/T$, for the 17 hexenes, for the ideal gaseous state, to 1,500°K.

Compound (gas)	Formula	Temperature ^a in °K							
		0	298.16	300	400	500	600	700	800
		Free-energy function, ^b $(F^\circ - H_0^\circ)/T$, in cal/deg mole							
1-Hexene.....	C ₆ H ₁₂	0	-70.85	-70.98	-77.7	-83.8	-89.5	-94.8	-99.9
<i>cis</i> -2-Hexene.....	C ₆ H ₁₂	0	-72.30	-72.42	-78.7	-84.4	-89.8	-94.9	-99.7
<i>trans</i> -2-Hexene.....	C ₆ H ₁₂	0	-70.33	-70.47	-77.1	-83.1	-88.7	-94.0	-99.1
<i>cis</i> -3-Hexene.....	C ₆ H ₁₂	0	-71.44	-71.54	-77.7	-83.6	-88.4	-93.4	-98.2
<i>trans</i> -3-Hexene.....	C ₆ H ₁₂	0	-69.53	-69.66	-76.2	-82.1	-87.6	-92.9	-98.0
2-Methyl-1-pentene.....	C ₆ H ₁₂	0	-70.75	-70.88	-77.4	-83.4	-88.9	-94.2	-99.2
3-Methyl-1-pentene.....	C ₆ H ₁₂	0	-70.32	-70.44	-76.8	-82.9	-88.5	-93.9	-99.0
4-Methyl-1-pentene.....	C ₆ H ₁₂	0	-69.95	-70.07	-76.4	-82.2	-87.7	-92.9	-98.0
2-Methyl-2-pentene.....	C ₆ H ₁₂	0	-71.40	-71.51	-77.6	-83.1	-88.3	-93.4	-98.2
<i>cis</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	0	-71.40	-71.51	-77.6	-83.1	-88.3	-93.4	-98.2
<i>trans</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	0	-72.21	-72.32	-78.4	-83.9	-89.2	-94.2	-99.0
<i>cis</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	0	-69.72	-69.83	-76.0	-81.8	-87.2	-92.4	-97.3
<i>trans</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	0	-67.69	-67.81	-74.3	-80.3	-85.9	-91.2	-96.3
2-Ethyl-1-butene.....	C ₆ H ₁₂	0	-70.20	-70.31	-76.7	-82.4	-87.9	-93.1	-98.1
2,3-Dimethyl-1-butene.....	C ₆ H ₁₂	0	-67.36	-67.48	-73.9	-79.9	-85.6	-90.9	-96.0
3,3-Dimethyl-1-butene.....	C ₆ H ₁₂	0	-65.08	-65.19	-71.4	-77.1	-82.4	-87.5	-92.4
2,3-Dimethyl-2-butene.....	C ₆ H ₁₂	0	-67.56	-67.68	-73.8	-79.3	-84.5	-89.5	-94.3

Compound (gas)	Formula	Temperature ^a in °K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Free-energy function, ^b $(F^\circ - H_0^\circ)/T$, in cal/deg mole						
1-Hexene.....	C ₆ H ₁₂	-104.8	-109.5	-113.9	-118.2	-122.3	-126.3	-130.1
<i>cis</i> -2-Hexene.....	C ₆ H ₁₂	-104.4	-108.9	-----	-----	-----	-----	-----
<i>trans</i> -2-Hexene.....	C ₆ H ₁₂	-103.9	-108.5	-----	-----	-----	-----	-----
<i>cis</i> -3-Hexene.....	C ₆ H ₁₂	-102.9	-107.3	-----	-----	-----	-----	-----
<i>trans</i> -3-Hexene.....	C ₆ H ₁₂	-102.8	-107.4	-----	-----	-----	-----	-----
2-Methyl-1-pentene.....	C ₆ H ₁₂	-104.1	-108.7	-----	-----	-----	-----	-----
3-Methyl-1-pentene.....	C ₆ H ₁₂	-103.9	-108.5	-----	-----	-----	-----	-----
4-Methyl-1-pentene.....	C ₆ H ₁₂	-102.8	-107.4	-----	-----	-----	-----	-----
2-Methyl-2-pentene.....	C ₆ H ₁₂	-102.8	-107.3	-----	-----	-----	-----	-----
<i>cis</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	-102.8	-107.3	-----	-----	-----	-----	-----
<i>trans</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	-103.6	-108.1	-----	-----	-----	-----	-----
<i>cis</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	-102.1	-106.6	-----	-----	-----	-----	-----
<i>trans</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	-101.1	-105.7	-----	-----	-----	-----	-----
2-Ethyl-1-butene.....	C ₆ H ₁₂	-102.8	-107.4	-----	-----	-----	-----	-----
2,3-Dimethyl-1-butene.....	C ₆ H ₁₂	-100.9	-105.5	-----	-----	-----	-----	-----
3,3-Dimethyl-1-butene.....	C ₆ H ₁₂	-97.2	-101.9	-----	-----	-----	-----	-----
2,3-Dimethyl-2-butene.....	C ₆ H ₁₂	-98.9	-103.3	-----	-----	-----	-----	-----

^a See footnote "a" of table 3.^b The free-energy function, $(F^\circ - H_0^\circ)/T$, is the free energy at the given temperature less the heat content at 0°K, divided by the absolute temperature (°K), of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere).

TABLE 8.—Values ^a of the free-energy function, $(F^\circ - H_0^\circ)/T$,^{°K} for the higher 1-alkenes, for the ideal gaseous state,^b to 1,500° K

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Free-energy function, ^b $(F^\circ - H_0^\circ)/T$, in cal/deg mole							
1-Heptene.....	C ₇ H ₁₄	0	-76.60	-76.76	-84.6	-91.7	-98.3	-104.6	-110.6
1-Octene.....	C ₈ H ₁₆	0	-82.35	-82.54	-91.5	-99.6	-107.2	-114.4	-121.2
1-Nonene.....	C ₉ H ₁₈	0	-88.10	-88.31	-98.3	-107.5	-116.0	-124.1	-131.8
1-Decene.....	C ₁₀ H ₂₀	0	-93.85	-94.09	-105.2	-115.3	-124.9	-133.9	-142.5
1-Undecene.....	C ₁₁ H ₂₂	0	-99.60	-99.86	-112.1	-123.2	-133.7	-143.6	-153.1
1-Dodecene.....	C ₁₂ H ₂₄	0	-105.35	-105.64	-118.9	-131.1	-142.5	-153.4	-163.7
1-Tridecene.....	C ₁₃ H ₂₆	0	-111.10	-111.41	-125.8	-139.0	-151.4	-163.1	-174.3
1-Tetradecene.....	C ₁₄ H ₂₈	0	-116.85	-117.19	-132.7	-146.9	-160.2	-172.9	-185.0
1-Pentadecene.....	C ₁₅ H ₃₀	0	-122.60	-122.96	-139.5	-154.8	-169.1	-182.6	-195.6
1-Hexadecene.....	C ₁₆ H ₃₂	0	-128.35	-128.74	-146.4	-162.7	-177.9	-192.4	-206.2
1-Heptadecene.....	C ₁₇ H ₃₄	0	-134.10	-134.51	-153.2	-170.5	-186.8	-202.1	-216.8
1-Octadecene.....	C ₁₈ H ₃₆	0	-139.85	-140.29	-160.1	-178.4	-195.6	-211.9	-227.5
1-Nonadecene.....	C ₁₉ H ₃₈	0	-145.60	-146.06	-167.0	-186.3	-204.5	-221.7	-238.1
1-Eicosene.....	C ₂₀ H ₄₀	0	-151.35	-151.84	-173.8	-194.2	-213.3	-231.4	-248.7
Δ per CH ₂		0	-5.750	-5.775	-6.87	-7.89	-8.85	-9.76	-10.63

Compound (gas)	Formula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Free-energy function, ^b $(F^\circ - H_0^\circ)/T$, in cal/deg mole						
1-Heptene.....	C ₇ H ₁₄	-116.3	-121.7	-127.0	-132.0	-136.8	-141.4	-145.9
1-Octene.....	C ₈ H ₁₆	-127.7	-134.0	-140.0	-145.7	-151.2	-156.5	-161.7
1-Nonene.....	C ₉ H ₁₈	-139.2	-146.3	-153.0	-159.5	-165.7	-171.7	-177.4
1-Decene.....	C ₁₀ H ₂₀	-150.7	-158.5	-166.0	-173.2	-180.2	-186.8	-193.2
1-Undecene.....	C ₁₁ H ₂₂	-162.1	-170.8	-179.1	-187.0	-194.6	-202.0	-209.0
1-Dodecene.....	C ₁₂ H ₂₄	-173.6	-183.0	-192.1	-200.8	-209.1	-217.1	-224.7
1-Tridecene.....	C ₁₃ H ₂₆	-185.0	-195.3	-205.1	-214.5	-223.6	-232.2	-240.5
1-Tetradecene.....	C ₁₄ H ₂₈	-196.5	-207.6	-218.2	-228.3	-238.1	-247.4	-256.3
1-Pentadecene.....	C ₁₅ H ₃₀	-208.0	-219.8	-231.2	-242.0	-252.5	-262.5	-272.0
1-Hexadecene.....	C ₁₆ H ₃₂	-219.4	-232.1	-244.2	-255.8	-267.0	-277.7	-287.8
1-Heptadecene.....	C ₁₇ H ₃₄	-230.9	-244.3	-257.3	-269.6	-281.5	-292.8	-303.6
1-Octadecene.....	C ₁₈ H ₃₆	-242.3	-256.6	-270.3	-283.3	-295.9	-307.9	-319.4
1-Nonadecene.....	C ₁₉ H ₃₈	-253.8	-268.9	-283.3	-297.1	-310.4	-323.1	-335.1
1-Eicosene.....	C ₂₀ H ₄₀	-265.3	-281.1	-296.3	-310.8	-324.9	-338.2	-350.9
Δ per CH ₂		-11.46	-12.26	-13.03	-13.76	-14.47	-15.14	-15.77

^a See footnote "a" of table 3.^b The free-energy function, $(F^\circ - H_0^\circ)/T$, is the free energy at the given temperature less the heat content at 0° K, divided by the absolute temperature (° K), of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere).

TABLE 9.—Values ^a of the entropy, S° , for the six pentenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Entropy, ^b S° , in cal/deg mole							
1-Pentene.....	C ₅ H ₁₀	0	83.08	83.25	92.13	100.41	108.21	115.53	122.42
cis-2-Pentene.....	C ₅ H ₁₀	0	82.76	82.89	90.97	98.68	106.11	113.21	119.90
trans-2-Pentene.....	C ₅ H ₁₀	0	81.81	81.97	90.67	98.77	106.45	113.68	120.51
2-Methyl-1-butene.....	C ₅ H ₁₀	0	81.73	81.88	90.61	98.76	106.49	113.77	120.61
3-Methyl-1-butene.....	C ₅ H ₁₀	0	79.70	79.86	88.94	97.54	105.48	112.87	119.79
2-Methyl-2-butene.....	C ₅ H ₁₀	0	80.90	81.06	89.39	97.18	104.65	111.75	118.46

Compound (gas)	Formula	Temperature ^a in ° K							
		900	1,000	1,100	1,200	1,300	1,400	1,500	
		Entropy, ^b S° , in cal/deg mole							
1-Pentene.....	C ₅ H ₁₀	128.90	135.03	140.82	146.30	151.50	156.46	161.20	
cis-2-Pentene.....	C ₅ H ₁₀	126.27	132.32	138.04	143.46	148.64	153.56	158.29	
trans-2-Pentene.....	C ₅ H ₁₀	126.93	133.03	138.79	144.26	149.45	154.39	159.11	
2-Methyl-1-butene.....	C ₅ H ₁₀	127.07	133.19	138.99	144.45	149.66	154.62	159.35	
3-Methyl-1-butene.....	C ₅ H ₁₀	126.31	132.45	138.27	143.76	148.99	153.95	158.70	
2-Methyl-2-butene.....	C ₅ H ₁₀	124.80	130.82	136.54	141.97	147.14	152.05	156.76	

^a See footnote "a" of table 3.^b S° is the entropy (exclusive of nuclear spin) of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere) at the temperature indicated.

TABLE 10.—Values ^a of the entropy, S° , for the 17 hexenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Entropy ^b , S° , in cal/deg mole							
1-Hexene.....	C ₆ H ₁₂	0	92.25	92.44	103.2	113.2	122.6	131.4	139.7
<i>cis</i> -2-Hexene.....	C ₆ H ₁₂	0	92.35	92.53	102.5	112.0	121.1	129.7	137.8
<i>trans</i> -2-Hexene.....	C ₆ H ₁₂	0	91.40	91.60	102.2	112.1	121.4	130.2	138.5
<i>cis</i> -3-Hexene.....	C ₆ H ₁₂	0	90.73	91.78	100.7	110.6	119.2	126.8	136.0
<i>trans</i> -3-Hexene.....	C ₆ H ₁₂	0	90.04	90.23	100.9	110.8	120.1	129.0	137.3
2-Methyl-1-pentene.....	C ₆ H ₁₂	0	91.32	91.51	102.1	112.1	121.4	130.3	138.5
3-Methyl-1-pentene.....	C ₆ H ₁₂	0	90.45	90.65	101.6	112.0	121.5	130.5	138.9
4-Methyl-1-pentene.....	C ₆ H ₁₂	0	89.58	89.77	100.5	110.5	120.0	128.9	137.3
<i>cis</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	0	90.45	90.62	100.6	110.1	119.2	127.8	135.9
<i>trans</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	0	91.26	91.43	101.4	110.9	120.0	128.6	136.8
<i>cis</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	0	89.23	89.41	99.8	109.7	119.0	127.7	135.9
<i>trans</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	0	88.02	88.21	99.1	109.2	118.7	127.5	135.8
2-Ethyl-1-butene.....	C ₆ H ₁₂	0	90.01	90.18	100.7	110.5	119.9	128.7	137.0
2,3-Dimethyl-1-butene.....	C ₆ H ₁₂	0	87.39	87.58	98.6	108.9	118.6	127.5	135.8
3,3-Dimethyl-1-butene.....	C ₆ H ₁₂	0	83.79	83.94	94.7	104.6	114.1	123.0	131.5
2,3-Dimethyl-2-butene.....	C ₆ H ₁₂	0	86.67	86.84	96.8	106.2	115.2	123.7	131.8

Compound (gas)	Formula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Entropy, ^b S° , in cal/deg mole						
1-Hexene.....	C ₆ H ₁₂	147.6	155.0	161.9	168.6	174.9	180.9	186.6
<i>cis</i> -2-Hexene.....	C ₆ H ₁₂	145.5	152.9	-----	-----	-----	-----	-----
<i>trans</i> -2-Hexene.....	C ₆ H ₁₂	146.2	153.6	-----	-----	-----	-----	-----
<i>cis</i> -3-Hexene.....	C ₆ H ₁₂	143.7	151.0	-----	-----	-----	-----	-----
<i>trans</i> -3-Hexene.....	C ₆ H ₁₂	145.1	152.5	-----	-----	-----	-----	-----
2-Methyl-1-pentene.....	C ₆ H ₁₂	146.4	153.8	-----	-----	-----	-----	-----
3-Methyl-1-pentene.....	C ₆ H ₁₂	146.8	154.2	-----	-----	-----	-----	-----
4-Methyl-1-pentene.....	C ₆ H ₁₂	145.2	152.6	-----	-----	-----	-----	-----
2-Methyl-2-pentene.....	C ₆ H ₁₂	143.6	151.0	-----	-----	-----	-----	-----
<i>cis</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	143.6	151.0	-----	-----	-----	-----	-----
<i>trans</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	144.5	151.8	-----	-----	-----	-----	-----
<i>cis</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	143.7	151.0	-----	-----	-----	-----	-----
<i>trans</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	143.6	151.0	-----	-----	-----	-----	-----
2-Ethyl-1-butene.....	C ₆ H ₁₂	144.8	152.2	-----	-----	-----	-----	-----
2,3-Dimethyl-1-butene.....	C ₆ H ₁₂	143.7	151.1	-----	-----	-----	-----	-----
3,3-Dimethyl-1-butene.....	C ₆ H ₁₂	139.5	147.0	-----	-----	-----	-----	-----
2,3-Dimethyl-2-butene.....	C ₆ H ₁₂	139.4	146.7	-----	-----	-----	-----	-----

^a See footnote "a" of table 3.^b S° is the entropy (exclusive of nuclear spin) of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere) at the temperature indicated.

TABLE 11.—Values ^a of the entropy, S° , for the higher 1-alkenes for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Entropy, ^b S° , in cal/deg mole							
1-Heptene.....	C ₇ H ₁₄	0	101.43	101.67	114.3	126.0	137.0	147.4	157.2
1-Octene.....	C ₈ H ₁₆	0	110.61	110.89	125.3	138.8	151.4	163.4	174.6
1-Nonene.....	C ₉ H ₁₈	0	119.79	120.11	136.4	151.6	165.9	179.3	192.0
1-Decene.....	C ₁₀ H ₂₀	0	128.97	129.33	147.5	164.4	180.3	195.3	209.4
1-Undecene.....	C ₁₁ H ₂₂	0	138.15	138.55	158.6	177.2	194.7	211.3	226.8
1-Dodecene.....	C ₁₂ H ₂₄	0	147.33	147.77	169.6	190.0	209.2	227.2	244.2
1-Tridecene.....	C ₁₃ H ₂₆	0	156.51	156.99	180.7	202.8	223.6	243.2	261.6
1-Tetradecene.....	C ₁₄ H ₂₈	0	165.69	166.21	191.8	215.6	238.0	259.2	279.0
1-Pentadecene.....	C ₁₅ H ₃₀	0	174.87	175.43	202.9	228.4	252.5	275.2	296.4
1-Hexadecene.....	C ₁₆ H ₃₂	0	184.05	184.65	213.9	241.2	266.9	291.1	313.8
1-Heptadecene.....	C ₁₇ H ₃₄	0	193.23	193.87	225.0	254.0	281.3	307.1	331.2
1-Octadecene.....	C ₁₈ H ₃₆	0	202.41	203.09	236.1	266.8	295.7	323.1	348.6
1-Nonadecene.....	C ₁₉ H ₃₈	0	211.59	212.31	247.2	279.6	310.2	339.0	366.0
1-Eicosene.....	C ₂₀ H ₄₀	0	220.77	221.53	258.2	292.4	324.6	355.0	383.4
Δ per CH ₂	-----	0	9.180	9.220	11.08	12.80	14.43	15.97	17.40

Compound (gas)	Formula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Entropy, ^b S° , in cal/deg mole						
1-Heptene.....	C ₇ H ₁₄	166.3	175.0	183.2	191.0	198.3	205.3	212.0
1-Octene.....	C ₈ H ₁₆	185.1	195.1	204.5	213.4	221.8	229.8	237.4
1-Nonene.....	C ₉ H ₁₈	203.8	215.1	225.7	235.7	245.3	254.3	262.9
1-Decene.....	C ₁₀ H ₂₀	222.6	235.1	247.0	258.1	268.7	278.8	288.3
1-Undecene.....	C ₁₁ H ₂₂	241.3	255.2	268.2	280.5	292.2	303.3	313.7
1-Dodecene.....	C ₁₂ H ₂₄	260.1	275.2	289.5	302.9	315.7	327.8	339.2
1-Tridecene.....	C ₁₃ H ₂₆	278.9	295.3	310.7	325.3	339.2	352.3	364.6
1-Tetradecene.....	C ₁₄ H ₂₈	297.6	315.3	332.0	347.6	362.6	376.8	390.0
1-Pentadecene.....	C ₁₅ H ₃₀	316.4	335.3	353.2	370.0	386.1	401.3	415.5
1-Hexadecene.....	C ₁₆ H ₃₂	335.1	355.4	374.5	392.4	409.6	425.8	440.9
1-Heptadecene.....	C ₁₇ H ₃₄	353.9	375.4	395.7	414.8	433.0	450.2	466.3
1-Octadecene.....	C ₁₈ H ₃₆	372.6	395.5	417.0	437.2	456.5	474.7	491.7
1-Nonadecene.....	C ₁₉ H ₃₈	391.4	415.5	438.2	459.5	480.0	499.2	517.2
1-Eicosene.....	C ₂₀ H ₄₀	410.1	435.5	459.5	481.9	503.4	523.7	542.6
Δ per CH ₂	-----	18.76	20.04	21.25	22.38	23.47	24.49	25.43

^a See footnote "a" of table 3.

^b S° is the entropy (exclusive of nuclear spin) of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere) at the temperature indicated.

TABLE 12.—Values ^a of the heat content, ($H^\circ - H_0^\circ$), for the six pentenes, for the ideal gaseous state, to 1,500°K.

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Heat content, ^b (H°—H ₀), in cal/mole							
1-Pentene.....	C ₅ H ₁₀	0	5358	5406	8500	12230	16520	21280	26440
<i>cis</i> -2-Pentene.....	C ₅ H ₁₀	0	4845	4887	7696	11190	15280	19890	24910
<i>trans</i> -2-Pentene.....	C ₅ H ₁₀	0	5149	5196	8216	11880	16110	20800	25910
2-Methyl-1-butene.....	C ₅ H ₁₀	0	5000	5046	8080	11770	16010	20740	25870
3-Methyl-1-butene.....	C ₅ H ₁₀	0	5137	5187	8380	12210	16570	21370	26560
2-Methyl-2-butene.....	C ₅ H ₁₀	0	4884	4929	7820	11350	15460	20060	25100

Compound (gas)	Formula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Heat contact, ^b (H°—H ₀), in cal/mole						
1-Pentene.....	C ₅ H ₁₀	31930	37740	43820	50140	56670	63360	70220
<i>cis</i> -2-Pentene.....	C ₅ H ₁₀	30310	36050	42040	48290	54760	61400	68220
<i>trans</i> -2-Pentene.....	C ₅ H ₁₀	31370	37160	43210	49490	55980	62650	69500
2-Methyl-1-butene.....	C ₅ H ₁₀	31350	37150	43230	49520	56040	62750	69590
3-Methyl-1-butene.....	C ₅ H ₁₀	32090	37940	44040	50390	56930	63620	70460
2-Methyl-2-butene.....	C ₅ H ₁₀	30480	36200	42200	48440	54900	61540	68360

^a See footnote "a" of table 3.^b The heat-content function, $(H^\circ - H_0^\circ)/T$, is the heat content at the given temperature less the heat content at 0° K, divided by the absolute temperature (° K) of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere).

TABLE 13.—Values ^a of the heat content ($H^\circ - H_0^\circ$), for the 17 hexenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Heat content, ^b ($H^\circ - H_0^\circ$), in cal/mole							
1-Hexene.....	C ₆ H ₁₂	0	6381	6438	10180	14680	19900	25600	31860
<i>cis</i> -2-Hexene.....	C ₆ H ₁₂	0	5978	6033	9510	13800	18800	24400	30500
<i>trans</i> -2-Hexene.....	C ₆ H ₁₂	0	6282	6339	10030	14480	19600	25300	31500
<i>cis</i> -3-Hexene.....	C ₆ H ₁₂	0	5752	5808	9220	13490	18500	24100	30200
<i>trans</i> -3-Hexene.....	C ₆ H ₁₂	0	6115	6171	9860	14360	19500	25200	31500
2-Methyl-1-pentene.....	C ₆ H ₁₂	0	6133	6189	9890	14360	19500	25200	31500
3-Methyl-1-pentene.....	C ₆ H ₁₂	0	6002	6063	9910	14530	19800	25600	31900
4-Methyl-1-pentene.....	C ₆ H ₁₂	0	5853	5910	9620	14160	19400	25200	31500
2-Methyl-2-pentene.....	C ₆ H ₁₂	0	5680	5733	9210	13500	18500	24100	30200
<i>cis</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	0	5680	5733	9210	13500	18500	24100	30200
<i>trans</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	0	5680	5733	9210	13500	18500	24100	30200
<i>cis</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	0	5817	5874	9510	13950	19050	24700	30900
<i>trans</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	0	6062	6120	9910	14460	19700	25400	31600
2-Ethyl-1-butene.....	C ₆ H ₁₂	0	5907	5961	9610	14070	19200	24900	31100
2,3-Dimethyl-1-butene.....	C ₆ H ₁₂	0	5972	6030	9890	14520	19800	25600	31900
3,3-Dimethyl-1-butene.....	C ₆ H ₁₂	0	5579	5625	9300	13790	19000	24000	31300
2,3-Dimethyl-2-butene.....	C ₆ H ₁₂	0	5698	5748	9210	13450	18400	23900	30000

Compound (gas)	Formula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Heat content, ^b ($H^\circ - H_0^\circ$), in cal/mole						
1-Hexene.....	C ₆ H ₁₂	38500	45500	52800	60500	68300	76400	847000
<i>cis</i> -2-Hexene.....	C ₆ H ₁₂	37000	44000	---	---	---	---	---
<i>trans</i> -2-Hexene.....	C ₆ H ₁₂	38100	45100	---	---	---	---	---
<i>cis</i> -3-Hexene.....	C ₆ H ₁₂	36700	43700	---	---	---	---	---
<i>trans</i> -3-Hexene.....	C ₆ H ₁₂	38100	45100	---	---	---	---	---
2-Methyl-1-pentene.....	C ₆ H ₁₂	38100	45100	---	---	---	---	---
3-Methyl-1-pentene.....	C ₆ H ₁₂	38600	45700	---	---	---	---	---
4-Methyl-1-pentene.....	C ₆ H ₁₂	38100	45200	---	---	---	---	---
2-Methyl-2-pentene.....	C ₆ H ₁₂	36700	43700	---	---	---	---	---
<i>cis</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	36700	43700	---	---	---	---	---
<i>trans</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	36700	43700	---	---	---	---	---
<i>cis</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	37500	44500	---	---	---	---	---
<i>trans</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	38300	45300	---	---	---	---	---
2-Ethyl-1-butene.....	C ₆ H ₁₂	37800	44800	---	---	---	---	---
2,3-Dimethyl-1-butene.....	C ₆ H ₁₂	38500	45600	---	---	---	---	---
3,3-Dimethyl-1-butene.....	C ₆ H ₁₂	38000	45100	---	---	---	---	---
2,3-Dimethyl-2-butene.....	C ₆ H ₁₂	36500	43400	---	---	---	---	---

^a See footnote "a" of table 3.^b ($H^\circ - H_0^\circ$) is the heat content at the given temperature less the heat content at 0°K of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere).

TABLE 14.—Values^a of the heat content ($H^\circ - H_0^\circ$), for the higher 1-alkenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Heat content, ^b ($H^\circ - H_0^\circ$), in cal/mole							
1-Heptene.....	C ₇ H ₁₄	0	7403	7473	11860	17140	23220	30000	37300
1-Octene.....	C ₈ H ₁₆	0	8426	8508	13550	19000	26570	34300	42700
1-Nonene.....	C ₉ H ₁₈	0	9449	9540	15230	22060	29920	38700	48100
1-Decene.....	C ₁₀ H ₂₀	0	10471	10575	16920	24520	33270	43000	53500
1-Undecene.....	C ₁₁ H ₂₂	0	11494	11607	18600	26970	36620	47400	58900
1-Dodecene.....	C ₁₂ H ₂₄	0	12517	12642	20280	29430	39980	51700	64400
1-Tridecene.....	C ₁₃ H ₂₆	0	13539	13674	21970	31890	43330	56100	69800
1-Tetradecene.....	C ₁₄ H ₂₈	0	14562	14709	23650	34350	46680	60400	75200
1-Pentadecene.....	C ₁₅ H ₃₀	0	15585	15741	25340	36800	50030	64800	80600
1-Hexadecene.....	C ₁₆ H ₃₂	0	16608	16776	27020	39260	53380	69100	86000
1-Heptadecene.....	C ₁₇ H ₃₄	0	17630	17808	28700	41720	56730	73500	91500
1-Octadecene.....	C ₁₈ H ₃₆	0	18653	18843	30390	44180	60080	77800	96900
1-Nonadecene.....	C ₁₉ H ₃₈	0	19676	19875	32070	46630	63430	82200	102300
1-Eicosene.....	C ₂₀ H ₄₀	0	20698	20910	33760	49090	66780	86500	107700
Δ per CH ₂		0	1022.7	1033.5	1684	2458	3351	4350	5420

Compound (gas)	Formula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Heat content, ^b ($H^\circ - H_0^\circ$), in cal/mole						
1-Heptene.....	C ₇ H ₁₄	45000	53300	61900	70800	80000	89500	99200
1-Octene.....	C ₈ H ₁₆	51600	61100	70900	81200	91700	102600	113700
1-Nonene.....	C ₉ H ₁₈	58200	68800	80000	91500	103400	115700	128200
1-Decene.....	C ₁₀ H ₂₀	64700	76600	89000	101800	115100	128800	142700
1-Undecene.....	C ₁₁ H ₂₂	71300	84400	98000	112200	126800	141900	157200
1-Dodecene.....	C ₁₂ H ₂₄	77900	92200	107100	122500	138500	155000	171600
1-Tridecene.....	C ₁₃ H ₂₆	84400	100000	116100	132900	150200	168100	186100
1-Tetradecene.....	C ₁₄ H ₂₈	91000	107700	125200	143200	161900	181100	200600
1-Pentadecene.....	C ₁₅ H ₃₀	97600	115500	134200	153600	173600	194200	215100
1-Hexadecene.....	C ₁₆ H ₃₂	104100	123300	143300	163900	185300	207300	229600
1-Heptadecene.....	C ₁₇ H ₃₄	110700	131100	152300	174300	197000	220400	244100
1-Octadecene.....	C ₁₈ H ₃₆	117300	138900	161300	184600	208700	233500	258600
1-Nonadecene.....	C ₁₉ H ₃₈	123800	146600	170400	194900	220400	246600	273100
1-Eicosene.....	C ₂₀ H ₄₀	130400	154400	179400	205300	232100	259700	287600
Δ per CH ₂		6570	7780	9040	10340	11700	13090	14490

^a See footnote "a" of table 3.^b ($H^\circ - H_0^\circ$) is the heat content at the given temperature less the heat content at 0°K of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere).

TABLE 15.—Values ^a of the heat capacity, C_p° , for the six pentenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Heat capacity, ^b C_p° , in cal/deg mole							
1-Pentene.....	C_5H_{10}	0	27.39	27.56	34.20	40.25	45.36	49.72	53.48
cis-2-Pentene.....	C_5H_{10}	0	24.32	24.45	31.57	38.05	43.62	48.25	52.29
trans-2-Pentene.....	C_5H_{10}	0	26.80	26.92	33.57	39.57	44.70	49.14	52.98
2-Methyl-1-butene.....	C_5H_{10}	0	26.69	26.82	33.71	39.81	44.97	49.40	53.23
3-Methyl-1-butene.....	C_5H_{10}	0	28.35	28.47	35.26	40.97	45.90	50.15	53.85
2-Methyl-2-butene.....	C_5H_{10}	0	25.49	25.62	32.22	38.33	43.64	48.23	52.22

Compound (gas)	Formula	Temperature ^a in ° K							
		900	1,000	1,100	1,200	1,300	1,400	1,500	
		Heat capacity, ^b C_p° , in cal/deg mole							
1-Pentene.....	C_5H_{10}	56.76	59.61	62.08	64.26	66.13	67.78	69.18	
cis-2-Pentene.....	C_5H_{10}	55.76	58.78	61.38	63.66	65.61	67.32	68.81	
trans-2-Pentene.....	C_5H_{10}	56.31	59.23	61.75	63.96	65.87	67.54	68.98	
2-Methyl-1-butene.....	C_5H_{10}	56.54	59.44	61.93	64.13	66.02	67.68	69.12	
3-Methyl-1-butene.....	C_5H_{10}	57.03	59.83	62.28	64.42	66.28	67.89	69.32	
2-Methyl-2-butene.....	C_5H_{10}	55.67	58.68	61.28	63.56	65.52	67.23	68.71	

^a See footnote "a" of table 3.^b C_p° is the heat capacity at constant pressure of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere) at the temperature indicated.

TABLE 16.—Values ^a of the heat capacity, ^b C_p° , for the 17 hexenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	Form- ula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Heat capacity, ^b C_p° , in cal/deg mole							
1-Hexene.....	C ₆ H ₁₂	0	33.08	33.30	41.3	48.7	54.8	60.1	64.6
cis-2-Hexene.....	C ₆ H ₁₂	0	30.36	30.56	38.8	46.6	53.2	58.7	63.4
trans-2-Hexene.....	C ₆ H ₁₂	0	32.84	33.03	40.8	48.1	54.2	59.6	64.1
cis-3-Hexene.....	C ₆ H ₁₂	0	29.55	29.71	38.5	46.4	53.2	58.7	63.5
trans-3-Hexene.....	C ₆ H ₁₂	0	32.63	32.78	41.1	48.4	54.6	59.8	64.4
2-Methyl-1-pentene...	C ₆ H ₁₂	0	32.73	32.93	41.0	48.3	54.5	59.8	64.4
3-Methyl-1-pentene...	C ₆ H ₁₂	0	34.04	34.19	42.5	49.6	55.6	60.7	65.2
4-Methyl-1-pentene...	C ₆ H ₁₂	0	32.61	32.76	41.5	48.9	55.2	60.5	65.1
2-Methyl-2-pentene...	C ₆ H ₁₂	0	30.26	30.42	39.0	46.6	53.2	58.6	63.4
cis-3-Methyl-2-pentene	C ₆ H ₁₂	0	30.26	30.42	39.0	46.6	53.2	58.6	63.4
trans-3-Methyl-2-pen- tene.....	C ₆ H ₁₂	0	30.26	30.42	39.0	46.6	53.2	58.6	63.4
cis-4-Methyl-2-pentene	C ₆ H ₁₂	0	31.92	32.07	40.5	47.8	54.1	59.4	64.0
trans-4-Methyl-2-pen- tene.....	C ₆ H ₁₂	0	33.80	33.94	41.9	48.8	54.8	60.0	64.5
2-Ethyl-1-butene.....	C ₆ H ₁₂	0	31.92	32.08	40.7	48.2	54.5	59.8	64.4
2, 3-Dimethyl-1-bu- tene.....	C ₆ H ₁₂	0	34.29	34.44	42.6	49.5	55.4	60.5	65.0
3, 3-Dimethyl-1-bu- tene.....	C ₆ H ₁₂	0	31.72	31.87	40.6	48.4	55.0	60.6	65.3
2, 3-Dimethyl-2-bu- tene.....	C ₆ H ₁₂	0	30.48	30.63	38.6	46.1	52.5	58.0	62.9

Compound (gas)	Form- ula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Heat capacity, ^b C_p° , in cal/deg mole						
1-Hexene.....	C ₆ H ₁₂	68.6	72.0	74.9	77.6	79.8	81.8	83.4
cis-2-Hexene.....	C ₆ H ₁₂	67.6	71.2	-----	-----	-----	-----	-----
trans-2-Hexene.....	C ₆ H ₁₂	68.1	71.6	-----	-----	-----	-----	-----
cis-3-Hexene.....	C ₆ H ₁₂	67.6	71.2	-----	-----	-----	-----	-----
trans-3-Hexene.....	C ₆ H ₁₂	68.3	71.8	-----	-----	-----	-----	-----
2-Methyl-1-pentene.....	C ₆ H ₁₂	68.4	71.8	-----	-----	-----	-----	-----
3-Methyl-1-pentene.....	C ₆ H ₁₂	69.0	72.3	-----	-----	-----	-----	-----
4-Methyl-1-pentene.....	C ₆ H ₁₂	68.9	72.3	-----	-----	-----	-----	-----
2-Methyl-2-pentene.....	C ₆ H ₁₂	67.5	71.1	-----	-----	-----	-----	-----
cis-3-Methyl-2-pentene.....	C ₆ H ₁₂	67.5	71.1	-----	-----	-----	-----	-----
trans-3-Methyl-2-pentene.....	C ₆ H ₁₂	67.5	71.1	-----	-----	-----	-----	-----
cis-4-Methyl-2-pentene.....	C ₆ H ₁₂	68.0	71.5	-----	-----	-----	-----	-----
trans-4-Methyl-2-pentene.....	C ₆ H ₁₂	68.4	71.8	-----	-----	-----	-----	-----
2-Ethyl-1-butene.....	C ₆ H ₁₂	68.4	71.9	-----	-----	-----	-----	-----
2,3-Dimethyl-1-butene.....	C ₆ H ₁₂	68.8	72.2	-----	-----	-----	-----	-----
3,3-Dimethyl-1-butene.....	C ₆ H ₁₂	69.2	72.7	-----	-----	-----	-----	-----
2,3-Dimethyl-2-butene.....	C ₆ H ₁₂	67.0	70.7	-----	-----	-----	-----	-----

^a See footnote "a" of table 3.^b C_p° is the heat capacity at constant pressure of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere) at the temperature indicated.

TABLE 17.—Values^a of the heat capacity, C_p^* , for the higher 1-alkenes for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Heat capacity, ^b C_p^* , in cal/deg mole							
1-Heptene.....	C ₇ H ₁₄	0	38.84	39.11	48.4	57.1	64.3	70.5	75.8
1-Octene.....	C ₈ H ₁₆	0	44.60	44.92	55.6	63.5	73.8	80.8	86.9
1-Nonene.....	C ₉ H ₁₈	0	50.36	50.73	62.7	74.0	83.3	91.2	98.0
1-Decene.....	C ₁₀ H ₂₀	0	56.12	56.54	69.8	82.4	92.7	101.6	109.2
1-Undecene.....	C ₁₁ H ₂₂	0	61.88	62.35	77.0	90.9	102.2	111.9	120.3
1-Dodecene.....	C ₁₂ H ₂₄	0	67.64	68.16	84.1	99.3	111.7	122.3	131.5
1-Tridecene.....	C ₁₃ H ₂₆	0	73.40	73.97	91.2	107.7	121.1	132.7	142.6
1-Tetradecene.....	C ₁₄ H ₂₈	0	79.16	79.78	98.4	116.2	130.6	143.0	153.7
1-Pentadecene.....	C ₁₅ H ₃₀	0	84.92	85.59	105.5	124.6	140.1	153.4	164.9
1-Hexadecene.....	C ₁₆ H ₃₂	0	90.68	91.40	112.6	133.0	149.5	163.8	176.0
1-Heptadecene.....	C ₁₇ H ₃₄	0	96.44	97.21	119.8	141.5	159.0	174.1	187.2
1-Octadecene.....	C ₁₈ H ₃₆	0	102.20	103.02	126.9	149.9	168.5	184.5	198.3
1-Nonadecene.....	C ₁₉ H ₃₈	0	107.96	108.83	134.0	158.3	177.9	194.9	209.4
1-Eicosenene.....	C ₂₀ H ₄₀	0	113.72	114.64	141.2	166.8	187.4	205.2	220.6
Δ per CH ₂	-----	0	5.760	5.810	7.13	8.44	9.47	10.37	11.14

Compound (gas)	Formula	Temperature ^a in ° K							
		900	1,000	1,100	1,200	1,300	1,400	1,500	
		Heat capacity, ^b C_p^* , in cal/deg mole							
1-Heptene.....	C ₇ H ₁₄	80.4	84.4	87.8	90.8	93.5	95.8	97.7	
1-Octene.....	C ₈ H ₁₆	92.1	96.7	100.7	104.1	107.1	109.7	111.9	
1-Nonene.....	C ₉ H ₁₈	103.9	109.1	113.5	117.4	120.8	123.7	126.2	
1-Decene.....	C ₁₀ H ₂₀	115.7	121.5	126.4	130.7	134.5	137.7	140.4	
1-Undecene.....	C ₁₁ H ₂₂	127.5	133.8	139.2	144.0	148.2	151.7	154.7	
1-Dodecene.....	C ₁₂ H ₂₄	139.3	146.2	152.1	157.3	161.8	165.7	168.9	
1-Tridecene.....	C ₁₃ H ₂₆	151.1	158.6	165.0	170.6	175.5	179.7	183.2	
1-Tetradecene.....	C ₁₄ H ₂₈	162.9	170.9	177.8	183.9	189.2	193.7	197.4	
1-Pentadecene.....	C ₁₅ H ₃₀	174.7	183.3	190.7	197.2	202.8	207.7	211.7	
1-Hexadecene.....	C ₁₆ H ₃₂	186.5	195.7	203.5	210.5	216.5	221.7	225.9	
1-Heptadecene.....	C ₁₇ H ₃₄	198.3	208.1	216.4	223.7	230.2	235.7	240.2	
1-Octadecene.....	C ₁₈ H ₃₆	210.0	220.4	229.3	237.0	243.8	249.6	254.4	
1-Nonadecene.....	C ₁₉ H ₃₈	221.8	232.8	242.1	250.3	257.5	263.6	268.7	
1-Eicosenene.....	C ₂₀ H ₄₀	233.6	245.2	255.0	263.6	271.2	277.6	282.9	
Δ per CH ₂	-----	11.79	12.37	12.86	13.29	13.67	13.99	14.25	

^a See footnote "a" of table 3.^b C_p^* is the heat capacity at constant pressure of the given hydrocarbon in the thermodynamic standard gaseous state of unit fugacity (1 atmosphere).

TABLE 18.—Values ^a of the heat of formation, ΔH_f° , for the six monoolefins, C_2 to C_4 , for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Heat of formation ^b , ΔH_f° , in kcal/mole							
Ethene (ethylene)----	C_2H_4	14.522	12.496	12.482	11.766	11.138	10.600	10.142	9.760
Propene (propylene)---	C_3H_6	8.468	4.879	4.858	3.758	2.793	1.98	1.30	0.76
1-Butene-----	C_4H_8	5.158	0.280	0.254	-1.090	-2.215	-3.14	-3.88	-4.46
<i>cis</i> -2-Butene-----	C_4H_8	3.794	-1.362	-1.393	-2.996	-4.369	-5.51	-6.44	-7.17
<i>trans</i> -2-Butene-----	C_4H_8	2.506	-2.405	-2.432	-3.846	-5.074	-6.11	-6.95	-7.62
2-Methylpropene (isobutene)-----	C_4H_8	1.676	-3.343	-3.370	-4.736	-5.911	-6.88	-7.69	-8.31

Compound (gas)	Formula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Heat of formation, ^b ΔH_f° , in kcal/mole						
Ethene (ethylene)-----	C_2H_4	9.448	9.205	9.02	8.88	8.76	8.67	8.61
Propene (propylene)-----	C_3H_6	0.34	0.03	-0.18	-0.32	-0.42	-0.47	-0.48
1-Butene-----	C_4H_8	-4.89	-5.17	-5.34	-5.40	-5.42	-5.37	-5.29
<i>cis</i> -2-Butene-----	C_4H_8	-7.74	-8.14	-8.40	-8.55	-8.64	-8.66	-8.62
<i>trans</i> -2-Butene-----	C_4H_8	-8.12	-8.46	-8.69	-8.81	-8.87	-8.87	-8.82
2-Methylpropene (isobutene)-----	C_4H_8	-8.79	-9.12	-9.31	-9.40	-9.44	-9.42	-9.35

^a See footnote "a" in table 3.^b ΔH_f° represents the increment in heat content for the reaction of forming the given compound in the gaseous state from the elements carbon (solid, graphite) and hydrogen (gaseous), with all the reactants and products in their appropriate standard reference state at the temperature indicated.TABLE 19.—Values ^a of the heat of formation, ΔH_f° , for the six pentenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Heat of formation, ^b ΔH_f° , in kcal/mole							
1-Pentene-----	C_5H_{10}	+1.019	-5.000	-5.034	-6.65	-8.01	-9.10	-9.97	-10.64
<i>cis</i> -2-Pentene-----	C_5H_{10}	-0.178	-6.710	-6.750	-8.65	-10.24	-11.53	-12.56	-13.36
<i>trans</i> -2-Pentene-----	C_5H_{10}	-1.362	-7.590	-7.625	-9.31	-10.73	-11.89	-12.83	-13.55
2-Methyl-1-butene-----	C_5H_{10}	-2.303	-8.680	-8.716	-10.39	-11.79	-12.92	-13.38	-14.53
3-Methyl-1-butene-----	C_5H_{10}	-0.681	-6.920	-6.952	-8.47	-9.72	-10.75	-11.58	-12.22
2-Methyl-2-butene-----	C_5H_{10}	-3.677	-10.170	-10.207	-12.03	-13.58	-14.85	-15.88	-16.68

Compound (gas)	Formula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Heat of formation, ^b ΔH_f° , in kcal/mole						
1-Pentene-----	C_5H_{10}	-11.14	-11.44	-11.60	-11.63	-11.58	-11.47	-11.31
<i>cis</i> -2-Pentene-----	C_5H_{10}	-13.95	-14.33	-14.58	-14.67	-14.69	-14.63	-14.50
<i>trans</i> -2-Pentene-----	C_5H_{10}	-14.08	-14.40	-14.59	-14.66	-14.65	-14.56	-14.41
2-Methyl-1-butene-----	C_5H_{10}	-15.04	-15.36	-15.51	-15.56	-15.53	-15.41	-15.26
3-Methyl-1-butene-----	C_5H_{10}	-12.67	-12.94	-13.08	-13.08	-13.02	-12.92	-12.77
2-Methyl-2-butene-----	C_5H_{10}	-17.28	-17.68	-17.92	-18.02	-18.04	-17.98	-17.86

^a See footnote "a" of table 3.^b ΔH_f° represents the increment in heat content for the reaction of forming the given compound in the gaseous state from the elements carbon (solid, graphite) and hydrogen (gaseous), with all the reactants and products in their appropriate standard reference state at the temperature indicated.

TABLE 20—Values ^a of the heat of formation, ΔH_f° , for the 17 hexenes, for the ideal gaseous state, to 1,500°K

Compound (gas)	Form- ula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Heat of formation, ^b ΔH_f° , in kcal/mole							
1-Hexene.....	C ₆ H ₁₂	-2.69	-9.96	-10.00	-11.9	-13.5	-14.8	-15.8	-16.6
cis-2-Hexene.....	C ₆ H ₁₂	-3.89	-11.56	-11.61	-13.8	-15.6	-17.1	-18.2	-19.1
trans-2-Hexene.....	C ₆ H ₁₂	-5.19	-12.56	-12.60	-14.6	-16.2	-17.5	-18.6	-19.4
cis-3-Hexene.....	C ₆ H ₁₂	-3.66	-11.56	-11.61	-13.8	-15.7	-17.1	-18.3	-19.2
trans-3-Hexene.....	C ₆ H ₁₂	-5.02	-12.56	-12.60	-14.6	-16.2	-17.5	-18.5	-19.3
2-Methyl-1-pentene.....	C ₆ H ₁₂	-6.04	-13.56	-13.60	-15.6	-17.2	-18.5	-19.5	-20.3
cis-3-Methyl-1-pentene.....	C ₆ H ₁₂	-3.37	-11.02	-11.06	-12.9	-14.3	-15.5	-16.5	-17.2
4-Methyl-1-pentene.....	C ₆ H ₁₂	-3.86	-11.66	-11.70	-13.6	-15.2	-16.4	-17.4	-18.1
2-Methyl-2-pentene.....	C ₆ H ₁₂	-6.99	-14.96	-15.01	-17.2	-19.0	-20.5	-21.6	-22.5
cis-3-Methyl-2-pentene.....	C ₆ H ₁₂	-6.35	-14.32	-14.37	-16.5	-18.3	-19.8	-21.0	-21.9
trans-3-Methyl-2-pentene.....	C ₆ H ₁₂	-6.35	-14.32	-14.37	-16.5	-18.3	-19.8	-21.0	-21.9
cis-4-Methyl-2-pentene.....	C ₆ H ₁₂	-5.42	-13.26	-13.30	-15.3	-17.0	-18.3	-19.4	-20.2
trans-4-Methyl-2-pentene.....	C ₆ H ₁₂	-6.67	-14.26	-14.30	-16.2	-17.7	-19.0	-20.0	-20.8
2-Ethyl-1-butene.....	C ₆ H ₁₂	-5.17	-12.92	-12.96	-15.0	-16.6	-17.9	-19.0	-19.7
2,3-Dimethyl-1-butene.....	C ₆ H ₁₂	-7.10	-14.78	-14.82	-16.6	-18.1	-19.3	-20.2	-21.0
3,3-Dimethyl-1-butene.....	C ₆ H ₁₂	-6.18	-14.25	-14.30	-16.3	-17.9	-19.1	-20.0	-20.6
2,3-Dimethyl-2-butene.....	C ₆ H ₁₂	-7.96	-15.91	-15.96	-18.1	-20.0	-21.5	-22.8	-23.7

Compound (gas)	Form- ula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Heat of formation, ^b ΔH_f° , in kcal/mole						
1-Hexene.....	C ₆ H ₁₂	-17.1	-17.4	-17.6	-17.6	-17.5	-17.3	-17.0
cis-2-Hexene.....	C ₆ H ₁₂	-19.8	-20.2	-----	-----	-----	-----	-----
trans-2-Hexene.....	C ₆ H ₁₂	-20.0	-20.4	-----	-----	-----	-----	-----
cis-3-Hexene.....	C ₆ H ₁₂	-19.8	-20.2	-----	-----	-----	-----	-----
trans-3-Hexene.....	C ₆ H ₁₂	-19.8	-20.2	-----	-----	-----	-----	-----
2-Methyl-1-pentene.....	C ₆ H ₁₂	-20.9	-21.2	-----	-----	-----	-----	-----
3-Methyl-1-pentene.....	C ₆ H ₁₂	-17.7	-18.0	-----	-----	-----	-----	-----
4-Methyl-1-pentene.....	C ₆ H ₁₂	-18.6	-18.9	-----	-----	-----	-----	-----
2-Methyl-2-pentene.....	C ₆ H ₁₂	-23.2	-23.6	-----	-----	-----	-----	-----
cis-3-Methyl-2-pentene.....	C ₆ H ₁₂	-22.5	-22.9	-----	-----	-----	-----	-----
trans-3-Methyl-2-pentene.....	C ₆ H ₁₂	-22.5	-22.9	-----	-----	-----	-----	-----
cis-4-Methyl-2-pentene.....	C ₆ H ₁₂	-20.8	-21.2	-----	-----	-----	-----	-----
trans-4-Methyl-2-pentene.....	C ₆ H ₁₂	-21.3	-21.6	-----	-----	-----	-----	-----
2-Ethyl-1-butene.....	C ₆ H ₁₂	-20.3	-20.6	-----	-----	-----	-----	-----
2,3-Dimethyl-1-butene.....	C ₆ H ₁₂	-21.5	-21.8	-----	-----	-----	-----	-----
3,3-Dimethyl-1-butene.....	C ₆ H ₁₂	-21.0	-21.3	-----	-----	-----	-----	-----
2,3-Dimethyl-2-butene.....	C ₆ H ₁₂	-24.4	-24.8	-----	-----	-----	-----	-----

^a See footnote "a" of table 3.

^b ΔH_f° represents the increment in heat content for the reaction of forming the given compound in the gaseous state from the elements carbon (solid, graphite) and hydrogen (gaseous), with all the reactants and products in their appropriate standard reference state at the temperature indicated.

TABLE 21.—Values ^a of the heat of formation, ΔH_f° , for the higher 1-alkenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	For- mula	Temperature ^a in °K							
		0	298.16	300	400	500	600	700	800
		Heat of formation, ^b ΔH_f° , in kcal/mole							
1-Heptene.....	C ₇ H ₁₄	-6.37	-14.89	-14.94	-17.1	-19.0	-20.4	-21.6	-22.4
1-Octene.....	C ₈ H ₁₆	-10.04	-19.82	-19.87	-22.4	-24.4	-26.1	-27.4	-28.3
1-Nonene.....	C ₉ H ₁₈	-13.71	-24.74	-24.80	-27.6	-29.9	-31.7	-33.1	-34.2
1-Decene.....	C ₁₀ H ₂₀	-17.39	-29.67	-29.73	-32.8	-35.4	-37.4	-38.9	-40.1
1-Undecene.....	C ₁₁ H ₂₂	-21.06	-34.60	-34.66	-38.0	-40.8	-43.0	-44.7	-45.9
1-Dodecene.....	C ₁₂ H ₂₄	-24.73	-39.52	-39.59	-43.3	-46.3	-48.7	-50.5	-51.8
1-Tridecene.....	C ₁₃ H ₂₆	-28.41	-44.45	-44.52	-48.5	-51.8	-54.3	-56.3	-57.7
1-Tetradecene.....	C ₁₄ H ₂₈	-32.08	-49.38	-49.45	-53.7	-57.2	-60.0	-62.0	-63.5
1-Pentadecene.....	C ₁₅ H ₃₀	-35.75	-54.31	-54.38	-58.9	-62.7	-65.6	-67.8	-69.4
1-Hexadecene.....	C ₁₆ H ₃₂	-39.42	-59.23	-59.31	-64.1	-68.2	-71.3	-73.6	-75.3
1-Heptadecene.....	C ₁₇ H ₃₄	-43.10	-64.15	-64.25	-69.4	-73.6	-76.9	-79.4	-81.2
1-Octadecene.....	C ₁₈ H ₃₆	-46.77	-69.08	-69.18	-74.6	-79.1	-82.6	-85.1	-87.0
1-Nonadecene.....	C ₁₉ H ₃₈	-50.44	-74.00	-74.11	-79.8	-84.6	-88.2	-90.9	-92.9
1-Eicosene.....	C ₂₀ H ₄₀	-54.12	-78.93	-79.04	-85.0	-90.0	-93.9	-96.7	-98.8
Δ per CH ₂		-3.673	-4.926	-4.931	-5.22	-5.47	-5.65	-5.78	-5.87

Compound (gas)	For- mula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Heat of formation, ^b ΔH_f° , in kcal/mole						
1-Heptene.....	C ₇ H ₁₄	-23.1	-23.4	-23.5	-23.5	-23.3	-23.0	-22.7
1-Octene.....	C ₈ H ₁₆	-29.0	-29.3	-29.4	-29.3	-29.1	-28.8	-28.4
1-Nonene.....	C ₉ H ₁₈	-34.9	-35.3	-35.4	-35.2	-35.0	-34.6	-34.1
1-Decene.....	C ₁₀ H ₂₀	-40.8	-41.2	-41.3	-41.1	-40.8	-40.3	-39.8
1-Undecene.....	C ₁₁ H ₂₂	-46.8	-47.1	-47.2	-47.0	-46.6	-46.1	-45.5
1-Dodecene.....	C ₁₂ H ₂₄	-52.8	-53.1	-53.1	-52.9	-52.5	-51.8	-51.2
1-Tridecene.....	C ₁₃ H ₂₆	-58.6	-59.0	-59.1	-58.8	-58.3	-57.6	-56.9
1-Tetradecene.....	C ₁₄ H ₂₈	-64.5	-65.0	-65.0	-64.7	-64.1	-63.4	-62.6
1-Pentadecene.....	C ₁₅ H ₃₀	-70.5	-70.9	-70.9	-70.5	-69.9	-69.1	-68.3
1-Hexadecene.....	C ₁₆ H ₃₂	-76.4	-76.9	-76.9	-76.4	-75.8	-74.9	-74.0
1-Heptadecene.....	C ₁₇ H ₃₄	-82.3	-82.8	-82.8	-82.3	-81.6	-80.6	-79.7
1-Octadecene.....	C ₁₈ H ₃₆	-88.3	-88.7	-88.7	-88.2	-87.4	-86.4	-85.3
1-Nonadecene.....	C ₁₉ H ₃₈	-94.2	-94.7	-94.6	-94.1	-93.3	-92.1	-91.0
1-Eicosene.....	C ₂₀ H ₄₀	-100.1	-100.6	-100.6	-100.0	-99.1	-97.9	-96.7
Δ per CH ₂		-5.93	-5.94	-5.93	-5.89	-5.83	-5.76	-5.69

^a See footnote "a" of table 3.^b ΔH_f° represents the increment in heat content for the reaction of forming the given compound in the gaseous state from the elements carbon (solid, graphite) and hydrogen (gaseous), with all the reactants and products in their appropriate standard reference states at the temperature indicated.

TABLE 22.—Values ^a of the free energy of formation, ΔF_f° , for the six monoolefins, C_2 to C_4 , for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in °K							
		0	298.16	300	400	500	600	700	800
		Free energy of formation, ^b ΔF_f° , kcal/mole							
Ethene (ethylene).....	C_2H_4	14.522	16.282	16.305	17.675	19.245	20.918	22.676	24.490
Propene (propylene)...	C_3H_6	8.468	14.990	15.051	18.610	22.450	26.46	30.59	34.81
1-Butene.....	C_4H_8	5.158	17.217	17.320	23.205	29.430	35.85	42.41	49.05
<i>cis</i> -2-Butene.....	C_4H_8	3.794	16.046	16.154	22.232	28.730	35.46	42.37	49.39
<i>trans</i> -2-Butene.....	C_4H_8	2.506	15.315	15.424	21.578	28.100	34.83	41.72	48.71
2-Methylpropene (isobutene).....	C_4H_8	1.676	14.582	14.693	20.910	27.480	34.25	41.17	48.19

Compound (gas)	Formula	Temperature ^a in °K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Free energy of formation, ^b ΔF_f° , kcal/mole						
Ethene (ethylene).....	C_2H_4	26.354	28.249	30.16	32.09	34.03	35.97	37.92
Propene (propylene).....	C_3H_6	39.10	43.43	47.78	52.15	56.52	60.90	65.28
1-Butene.....	C_4H_8	55.78	62.54	69.31	76.10	82.90	89.67	96.46
<i>cis</i> -2-Butene.....	C_4H_8	56.50	63.66	70.84	78.06	85.29	92.51	99.74
<i>trans</i> -2-Butene.....	C_4H_8	55.80	62.93	70.08	77.25	84.43	91.59	98.77
2-Methylpropene (isobutene).....	C_4H_8	55.28	62.42	69.58	76.76	83.96	91.13	98.31

^a See footnote "a" in table 3.^b ΔF_f° represents the increment in free energy for the reaction of forming the given compound in the gaseous state from the elements carbon (solid, graphite) and hydrogen (gaseous), with all the reactants and products in their appropriate standard reference states at the temperature indicated.TABLE 23.—Values ^a of the free energy of formation, ΔF_f° , for the six pentenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in °K							
		0	298.16	300	400	500	600	700	800
		Free energy of formation, ^b ΔF_f° , in kcal/mole							
1-Pentene.....	C_5H_{10}	1.019	18.787	18.930	27.16	35.78	44.65	53.69	62.81
<i>cis</i> -2-Pentene.....	C_5H_{10}	-0.178	17.173	17.322	25.62	34.41	43.48	52.72	62.11
<i>trans</i> -2-Pentene.....	C_5H_{10}	-1.362	16.575	16.723	25.08	33.87	42.91	52.12	61.43
2-Methyl-1-Butene.....	C_5H_{10}	-2.303	15.509	15.659	24.03	32.82	41.85	51.06	60.37
3-Methyl-1-Butene.....	C_5H_{10}	-0.681	17.874	18.029	26.62	35.50	44.63	53.94	63.34
2-Methyl-2-Butene.....	C_5H_{10}	-3.677	14.267	14.414	22.88	31.82	41.03	50.42	59.94

Compound (gas)	Formula	Temperature ^a in °K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Free energy of formation, ^b ΔF_f° , in kcal/mole						
1-Pentene.....	C_5H_{10}	72.02	81.27	90.55	99.86	109.19	118.46	127.71
<i>cis</i> -2-Pentene.....	C_5H_{10}	71.58	81.10	90.63	100.22	109.80	119.36	128.88
<i>trans</i> -2-Pentene.....	C_5H_{10}	70.86	80.31	89.79	99.28	108.78	118.25	127.74
2-Methyl-1-Butene.....	C_5H_{10}	69.76	79.20	88.65	98.14	107.63	117.10	126.53
3-Methyl-1-Butene.....	C_5H_{10}	72.82	82.35	91.88	101.46	111.01	120.52	130.00
2-Methyl-2-Butene.....	C_5H_{10}	69.57	79.25	88.94	98.66	108.39	118.12	127.81

^a See footnote "a" of table 3.^b ΔF_f° represents the increment in free energy for the reaction of forming the given compound in the gaseous state from the elements carbon (solid, graphite) and hydrogen (gaseous), with all the reactants and products in their appropriate standard reference states at the temperature indicated.

TABLE 24.—Values ^a of the free energy of formation, ΔF_f° , for the 17 hexenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Free energy of formation, ^b ΔF_f° , in kcal/mole							
1-Hexene	C ₆ H ₁₂	-2.69	20.80	20.99	31.6	42.7	54.1	65.6	77.3
<i>cis</i> -2-Hexene	C ₆ H ₁₂	-3.89	19.18	19.36	30.0	41.2	52.7	64.4	76.3
<i>trans</i> -2-Hexene	C ₆ H ₁₂	-5.19	18.46	18.65	29.3	40.5	52.0	63.7	75.5
<i>cis</i> -3-Hexene	C ₆ H ₁₂	-3.66	19.66	19.86	30.7	42.0	53.7	65.7	77.7
<i>trans</i> -3-Hexene	C ₆ H ₁₂	-5.02	18.86	19.06	29.9	41.2	52.8	64.6	76.6
2-Methyl-1-pentene	C ₆ H ₁₂	-6.04	17.48	17.67	28.4	39.6	51.1	62.7	74.5
3-Methyl-1-pentene	C ₆ H ₁₂	-3.37	20.28	20.47	31.3	42.5	54.0	65.6	77.4
4-Methyl-1-pentene	C ₆ H ₁₂	-3.86	19.90	20.09	31.0	42.3	54.0	65.8	77.7
2-Methyl-2-pentene	C ₆ H ₁₂	-6.99	16.34	16.54	27.4	38.8	50.5	62.4	74.4
<i>cis</i> -3-Methyl-2-pentene	C ₆ H ₁₂	-6.35	16.98	17.18	28.0	39.4	51.1	63.0	75.1
<i>trans</i> -3-Methyl-2-pentene	C ₆ H ₁₂	-6.35	16.74	16.93	27.7	39.0	50.6	62.4	74.4
<i>cis</i> -4-Methyl-2-pentene	C ₆ H ₁₂	-5.42	18.40	18.60	29.6	41.0	52.7	64.6	76.7
<i>trans</i> -4-Methyl-2-pentene	C ₆ H ₁₂	-6.67	17.77	17.96	29.0	40.5	52.2	64.2	76.2
2-Ethyl-1-butene	C ₆ H ₁₂	-5.17	18.51	18.71	29.6	40.9	52.5	64.4	76.3
2, 3-Dimethyl-1-butene	C ₆ H ₁₂	-7.10	17.43	17.63	28.7	40.2	52.0	64.0	76.0
3, 3-Dimethyl-1-butene	C ₆ H ₁₂	-6.18	19.04	19.25	30.7	42.6	54.9	67.3	79.9
2, 3-Dimethyl-2-butene	C ₆ H ₁₂	-7.96	16.52	16.72	27.9	39.7	51.8	64.1	76.6

Compound (gas)	Formula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Free energy of formation, ^b ΔF_f° , in kcal/mole						
1-Hexene	C ₆ H ₁₂	89.1	100.9	112.7	124.6	136.5	148.3	160.1
<i>cis</i> -2-Hexene	C ₆ H ₁₂	88.3	100.3	—	—	—	—	—
<i>trans</i> -2-Hexene	C ₆ H ₁₂	87.4	99.4	—	—	—	—	—
<i>cis</i> -3-Hexene	C ₆ H ₁₂	89.9	102.1	—	—	—	—	—
<i>trans</i> -3-Hexene	C ₆ H ₁₂	88.6	100.6	—	—	—	—	—
2-Methyl-1-pentene	C ₆ H ₁₂	86.4	98.3	—	—	—	—	—
3-Methyl-1-pentene	C ₆ H ₁₂	89.2	101.2	—	—	—	—	—
4-Methyl-1-pentene	C ₆ H ₁₂	89.7	101.8	—	—	—	—	—
2-Methyl-2-pentene	C ₆ H ₁₂	86.6	98.8	—	—	—	—	—
<i>cis</i> -3-Methyl-2-pentene	C ₆ H ₁₂	87.2	99.4	—	—	—	—	—
<i>trans</i> -3-Methyl-2-pentene	C ₆ H ₁₂	86.5	98.6	—	—	—	—	—
<i>cis</i> -4-Methyl-2-pentene	C ₆ H ₁₂	88.8	101.1	—	—	—	—	—
<i>trans</i> -4-Methyl-2-pentene	C ₆ H ₁₂	88.4	100.7	—	—	—	—	—
2-Ethyl-1-butene	C ₆ H ₁₂	88.4	100.5	—	—	—	—	—
2, 3-Dimethyl-1-butene	C ₆ H ₁₂	88.2	100.4	—	—	—	—	—
3, 3-Dimethyl-1-butene	C ₆ H ₁₂	92.4	105.0	—	—	—	—	—
2, 3-Dimethyl-2-butene	C ₆ H ₁₂	89.2	101.8	—	—	—	—	—

^a See footnote "a" of table 3.^b ΔF_f° represents the increment in free energy for the reaction of forming the given compound in the gaseous state from the elements carbon (solid, graphite) and hydrogen (gaseous), with all the reactants and products their appropriate standard reference states at the temperature indicated.

TABLE 25.—Values^a of the free energy of formation, ΔF_f° , for the higher 1-alkenes, for the ideal gaseous state, to 1,500°K

Compound (gas)	Formula	Temperature in °K °							
		0	298.16	300	400	500	600	700	800
		Free energy of formation, ^b ΔF_f° , in kcal/mole							
1-Heptene.....	C ₇ H ₁₄	-6.37	22.84	23.08	36.1	49.6	63.5	77.6	91.8
1-Octene.....	C ₈ H ₁₆	-10.04	24.89	25.17	40.6	56.6	72.9	89.5	106.3
1-Nonene.....	C ₉ H ₁₈	-13.71	26.94	27.26	45.1	63.5	82.4	101.5	120.8
1-Decene.....	C ₁₀ H ₂₀	-17.39	28.99	29.35	49.5	70.4	91.8	113.4	135.2
1-Undecene.....	C ₁₁ H ₂₂	-21.06	31.03	31.44	54.0	77.4	101.2	125.4	149.7
1-Dodecene.....	C ₁₂ H ₂₄	-24.73	33.08	33.53	58.5	84.3	110.6	137.3	164.2
1-Tridecene.....	C ₁₃ H ₂₆	-28.41	35.13	35.62	63.0	91.2	120.1	149.3	178.7
1-Tetradecene.....	C ₁₄ H ₂₈	-32.08	37.18	37.71	67.4	98.2	129.5	161.2	193.2
1-Pentadecene.....	C ₁₅ H ₃₀	-35.75	39.23	39.80	71.9	105.1	138.9	173.2	207.7
1-Hexadecene.....	C ₁₆ H ₃₂	-39.42	41.27	41.89	76.4	112.0	148.3	185.1	222.1
1-Heptadecene.....	C ₁₇ H ₃₄	-43.10	43.32	43.98	80.9	118.9	157.8	197.1	236.6
1-Octadecene.....	C ₁₈ H ₃₆	-46.77	45.37	46.07	85.4	125.9	167.2	209.0	251.1
1-Nonadecene.....	C ₁₉ H ₃₈	-50.44	47.42	48.16	89.8	132.8	176.6	221.0	265.6
1-Eicosene.....	C ₂₀ H ₄₀	-54.12	49.47	50.25	94.3	139.7	186.1	232.9	280.1
Δ per CH ₂		-3.673	2.048	2.090	4.47	6.93	9.43	11.95	14.48

Compound (gas)	Formula	Temperature ^a in °K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Free energy of formation, ^b ΔF_f° , in kcal/mole						
1-Heptene.....	C ₇ H ₁₄	106.1	120.5	134.8	149.2	163.7	178.0	192.4
1-Octene.....	C ₈ H ₁₆	123.1	140.0	157.0	173.9	190.9	207.8	224.7
1-Nonene.....	C ₉ H ₁₈	140.2	159.6	179.1	198.6	218.1	237.6	257.1
1-Decene.....	C ₁₀ H ₂₀	157.2	179.2	201.2	223.3	245.3	267.3	289.4
1-Undecene.....	C ₁₁ H ₂₂	174.2	198.8	223.3	247.9	272.5	297.1	321.7
1-Dodecene.....	C ₁₂ H ₂₄	191.3	218.4	245.4	272.6	299.7	326.9	354.1
1-Tridecene.....	C ₁₃ H ₂₆	208.3	237.9	267.6	297.3	327.0	356.6	386.4
1-Tetradecene.....	C ₁₄ H ₂₈	225.3	257.5	289.7	321.9	354.2	386.4	418.7
1-Pentadecene.....	C ₁₅ H ₃₀	242.3	277.1	311.8	346.6	381.4	416.1	451.1
1-Hexadecene.....	C ₁₆ H ₃₂	259.4	296.7	333.9	371.3	408.6	445.9	483.4
1-Heptadecene.....	C ₁₇ H ₃₄	276.4	316.3	356.0	395.9	435.8	475.7	515.7
1-Octadecene.....	C ₁₈ H ₃₆	293.4	335.8	378.1	420.6	463.0	505.4	548.1
1-Nonadecene.....	C ₁₉ H ₃₈	310.5	355.4	400.3	445.3	490.3	535.2	580.4
1-Eicosene.....	C ₂₀ H ₄₀	327.5	375.0	422.4	469.9	517.5	565.0	612.7
Δ per CH ₂		17.03	19.58	22.12	24.67	27.22	29.76	32.33

^a See footnote "a" of table 3.^b ΔF_f° represents the increment in free energy for the reaction of forming the given compound in the gaseous state from the elements carbon (solid, graphite) and hydrogen (gaseous), with all the reactants and products in their appropriate standard reference states at the temperature indicated.

TABLE 26.—Values ^a of the logarithm of the equilibrium constant of formation, $\log_{10} K_f$, for the six monoolefins, C_2 to C_4 , for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Logarithm of equilibrium constant of formation, ^b $\log_{10} K_f$							
Ethene (ethylene)	C_2H_4	Infinite	-11.9345	-11.8781	-9.6571	-8.4119	-7.6193	-7.0797	-6.6903
Propene (propylene)	C_3H_6	do	-10.9875	-10.9648	-10.1677	-9.8128	-9.6375	-9.5519	-9.5093
1-Butene	C_4H_8	do	-12.6199	-12.6175	-12.6785	-12.8637	-13.0582	-13.2403	-13.4005
<i>cis</i> -2-Butene	C_4H_8	do	-11.7618	-11.7677	-12.1469	-12.5576	-12.9169	-13.2274	-13.4923
<i>trans</i> -2-Butene	C_4H_8	do	-11.2255	-11.2362	-11.7896	-12.2824	-12.6874	-13.0268	-13.3081
2-Methylpropene (Isobutene)	C_4H_8	do	-10.6888	-10.7038	-11.4244	-12.0112	-12.4763	-12.8533	-13.1649

Compound (gas)	Formula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Logarithm of equilibrium constant of formation, ^b $\log_{10} K_f$						
Ethene (ethylene)	C_2H_4	-6.3996	-6.1738	-5.9918	-5.8440	-5.7206	-5.6151	-5.5249
Propene (propylene)	C_3H_6	-9.4942	-9.4909	-9.4922	-9.4970	-9.5027	-9.5066	-9.5117
1-Butene	C_4H_8	-13.5442	-13.6669	-13.7707	-13.8598	-13.9358	-13.9986	-14.0537
<i>cis</i> -2-Butene	C_4H_8	-13.7200	-13.9126	-14.0749	-14.2166	-14.3389	-14.4417	-14.5321
<i>trans</i> -2-Butene	C_4H_8	-13.5498	-13.7526	-13.9226	-14.0688	-14.1938	-14.2979	-14.3901
2-Methylpropene (Isobutene)	C_4H_8	-13.4245	-13.6424	-13.8249	-13.9805	-14.1141	-14.2257	-14.3232

^a See footnote "a" in table 3.^b $\log_{10} K_f$ represents the logarithm (to the base 10) of the equilibrium constant for the reaction of forming the given compound in the gaseous state from the elements carbon (solid, graphite) and hydrogen (gaseous), with all the reactants and products in their appropriate standard reference states at the temperature indicated. $\log_{10} K_f = -\Delta F_f^\circ / 0.00457566T$; ΔF_f° in kcal/mole, T in °K.

TABLE 27.—Values ^a of the logarithm of the equilibrium constant of formation, $\log_{10} K_f$, for the six pentenes, for the ideal gaseous state, to 1,500°K

Compound (gas)	Formula	Temperature ^a in °K							
		0	298.16	300	400	500	600	700	800
		Logarithm of equilibrium constant of formation, ^b $\log_{10} K_f$							
1-Pentene	C ₅ H ₁₀	Infinite	-13.7704	-13.7904	-14.8394	-15.6377	-16.2629	-16.7617	-17.1601
<i>cis</i> -2-Pentene	C ₅ H ₁₀	do	-12.5874	-12.6191	-13.9997	-15.0403	-15.8357	-16.4901	-16.9665
<i>trans</i> -2-Pentene	C ₅ H ₁₀	do	-12.1495	-12.1824	-13.7022	-14.8045	-15.6315	-16.2717	-16.7827
2-Methyl-1-butene	C ₅ H ₁₀	do	-11.3680	-11.4073	-13.1269	-14.3451	-15.2451	-15.9408	-16.4929
3-Methyl-1-butene	C ₅ H ₁₀	do	-13.1017	-13.1337	-14.5425	-15.5156	-16.2580	-16.8408	-17.3034
2-Methyl-2-butene	C ₅ H ₁₀	do	-10.4572	-10.5005	-12.5009	-13.9086	-14.9457	-15.7414	-16.3755

Compound (gas)	Formula	Temperature ^a in °K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Logarithm of equilibrium constant of formation, ^b $\log_{10} K_f$						
1-Pentene	C ₅ H ₁₀	-17.4898	-17.7622	-17.9911	-18.1863	-18.3556	-18.4920	-18.6070
<i>cis</i> -2-Pentene	C ₅ H ₁₀	-17.3806	-17.7236	-18.0069	-18.2524	-18.4581	-18.6329	-18.7779
<i>trans</i> -2-Pentene	C ₅ H ₁₀	-17.2066	-17.5522	-17.8393	-18.0804	-18.2874	-18.4612	-18.6119
2-Methyl-1-butene	C ₅ H ₁₀	-16.9409	-17.3004	-17.6130	-17.8741	-18.0943	-18.2793	-18.4355
3-Methyl-1-butene	C ₅ H ₁₀	-17.6825	-17.9984	-18.2545	-18.4778	-18.6621	-18.8146	-18.9408
2-Methyl-2-butene	C ₅ H ₁₀	-16.8936	-17.3195	-17.6701	-17.9692	-18.2218	-18.4386	-18.6222

^a See footnote "a" of table 3.^b $\log_{10} K_f$ represents the logarithm (to the base 10) of the equilibrium constant for the reaction of forming the given compound in the gaseous state from the elements carbon (solid, graphite) and hydrogen (gaseous), with all the reactants and products in their appropriate standard reference states at the temperature indicated. $\log_{10} K_f = -\Delta F_f^\circ / 0.00457566 T$; ΔF_f° in kcal/mole, T in °K.

TABLE 28.—Values ^a of the logarithm of the equilibrium constant of formation, $\log_{10} K_f$, for the 17 hexenes, for the ideal gaseous state, to 1,500° K

Compound (gas)	Formula	Temperature, ^a in °K							
		0	298.16	300	400	500	600	700	800
		Logarithm of equilibrium constant of formation, ^b $\log_{10} K_f$							
1-Hexene.....	C ₆ H ₁₂	Infinite.	-15.2491	-15.2938	-17.2736	-18.6647	-19.6963	-20.4918	-21.1243
<i>cis</i> -2-Hexene.....	C ₆ H ₁₂	do.....	-14.0549	-14.1099	-16.3966	-18.0038	-19.1969	-20.1158	-20.8432
<i>trans</i> -2-Hexene.....	C ₆ H ₁₂	do.....	-13.5291	-13.5828	-16.0336	-17.7155	-18.9490	-19.8900	-20.6267
<i>cis</i> -3-Hexene.....	C ₆ H ₁₂	do.....	-14.4094	-14.4646	-16.7566	-18.3784	-19.5768	-20.4970	-21.2287
<i>trans</i> -3-Hexene.....	C ₆ H ₁₂	do.....	-13.8262	-13.8814	-16.3258	-18.0179	-19.2480	-20.1803	-20.9127
2-Methyl-1-pentene.....	C ₆ H ₁₂	do.....	-12.8135	-12.8733	-15.5074	-17.2955	-18.5953	-19.5871	-20.3614
3-Methyl-1-pentene.....	C ₆ H ₁₂	do.....	-14.8655	-14.9154	-17.1002	-18.5657	-19.6579	-20.4888	-21.1392
4-Methyl-1-pentene.....	C ₆ H ₁₂	do.....	-14.5865	-14.6386	-16.9303	-18.5053	-19.6670	-20.5432	-21.2302
2-Methyl-2-pentene.....	C ₆ H ₁₂	do.....	-11.9780	-12.0461	-14.9509	-16.9386	-18.3774	-19.4687	-20.3302
<i>cis</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	do.....	-12.4471	-12.5123	-15.3006	-17.2183	-18.6105	-19.6685	-20.5050
<i>trans</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	do.....	-12.2697	-12.3353	-15.1236	-17.0413	-18.4335	-19.4915	-20.3280
<i>cis</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	do.....	-13.4903	-13.5519	-16.1567	-17.9059	-19.1914	-20.1730	-20.9472
<i>trans</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	do.....	-13.0216	-13.0864	-15.8569	-17.6895	-19.0243	-20.0378	-20.8301
2-Ethyl-1-butene.....	C ₆ H ₁₂	do.....	-13.5690	-13.6292	-16.1492	-17.8819	-19.1405	-20.1093	-20.8539
2, 3-Dimethyl-1-butene.....	C ₆ H ₁₂	do.....	-12.7782	-12.8449	-15.7069	-17.5844	-18.9418	-19.9712	-20.7737
3, 3-Dimethyl-1-butene.....	C ₆ H ₁₂	do.....	-13.9578	-14.0211	-16.7485	-18.5996	-19.9697	-21.0179	-21.8171
2, 3-Dimethyl-2-butene.....	C ₆ H ₁₂	do.....	-12.1073	-12.1779	-15.2525	-17.3503	-18.8661	-20.0122	-20.9180

Compound (gas)	Formula	Temperature, ^a in °K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Logarithm of equilibrium constant of formation, ^b log ₁₀ <i>K</i> _f						
1-Hexene.....	C ₆ H ₁₂	-21.6299	-22.0483	-22.3959	-22.6900	-22.9410	-23.1468	-23.3230
<i>cis</i> -2-Hexene.....	C ₆ H ₁₂	-21.4310	-21.9115	-----	-----	-----	-----	-----
<i>trans</i> -2-Hexene.....	C ₆ H ₁₂	-21.2278	-21.7158	-----	-----	-----	-----	-----
<i>cis</i> -3-Hexene.....	C ₆ H ₁₂	-21.8205	-22.3040	-----	-----	-----	-----	-----
<i>trans</i> -3-Hexene.....	C ₆ H ₁₂	-21.5110	-21.9949	-----	-----	-----	-----	-----
2-Methyl-1-pentene.....	C ₆ H ₁₂	-20.9840	-21.4927	-----	-----	-----	-----	-----
3-Methyl-1-pentene.....	C ₆ H ₁₂	-21.6720	-22.1070	-----	-----	-----	-----	-----
4-Methyl-1-pentene.....	C ₆ H ₁₂	-21.7932	-22.2489	-----	-----	-----	-----	-----
2-Methyl-2-pentene.....	C ₆ H ₁₂	-21.0209	-21.5874	-----	-----	-----	-----	-----
<i>cis</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	-21.1763	-21.7273	-----	-----	-----	-----	-----
<i>trans</i> -3-Methyl-2-pentene.....	C ₆ H ₁₂	-20.9993	-21.5503	-----	-----	-----	-----	-----
<i>cis</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	-21.5665	-22.0864	-----	-----	-----	-----	-----
<i>trans</i> -4-Methyl-2-pentene.....	C ₆ H ₁₂	-21.4740	-22.0000	-----	-----	-----	-----	-----
2-Ethyl-1-butene.....	C ₆ H ₁₂	-21.4611	-21.9553	-----	-----	-----	-----	-----
2, 3-Dimethyl-1-butene.....	C ₆ H ₁₂	-21.4175	-21.9475	-----	-----	-----	-----	-----
3, 3-Dimethyl-1-butene.....	C ₆ H ₁₂	-22.4417	-22.9383	-----	-----	-----	-----	-----
2, 3-Dimethyl-2-butene.....	C ₆ H ₁₂	-21.6491	-22.2478	-----	-----	-----	-----	-----

^a See footnote "a" of table 3.

^b Log₁₀ K_f represents the logarithm (to the base 10) of the equilibrium constant for the reaction of forming the given compound in the gaseous state from the elements carbon (solid, graphite) and hydrogen (gaseous), with all the reactants and products in their appropriate standard reference states at the temperature indicated. Log₁₀ K_f = $-\Delta F_f^\circ / 0.00457566T$; ΔF_f° in kcal/mole, T in °K.

TABLE 29.—Values ^a of the logarithm of the equilibrium constant of formation, $\log_{10} K_f$, for the higher 1-alkenes, for the ideal gaseous state to 1,500° K

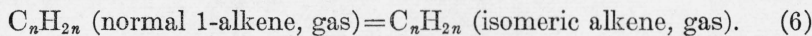
Compound (gas)	Formula	Temperature ^a in ° K							
		0	298.16	300	400	500	600	700	800
		Logarithm of equilibrium constant of formation, ^b log ₁₀ K _f							
1-Heptene.....	C ₇ H ₁₄	Infinite	-16.742	-16.814	-19.719	-21.693	-23.126	-24.221	-25.076
1-Octene.....	C ₈ H ₁₆	do	-18.244	-18.336	-22.166	-24.722	-26.561	-27.952	-29.031
1-Nonene.....	C ₉ H ₁₈	do	-19.747	-19.859	-24.614	-27.751	-29.996	-31.683	-32.987
1-Decene.....	C ₁₀ H ₂₀	do	-21.249	-21.381	-27.062	-30.780	-33.431	-35.414	-36.946
1-Undecene.....	C ₁₁ H ₂₂	do	-22.745	-22.904	-29.510	-33.809	-36.862	-39.145	-40.901
1-Dodecene.....	C ₁₂ H ₂₄	do	-24.247	-24.426	-31.957	-36.839	-40.297	-42.876	-44.860
1-Tridecene.....	C ₁₃ H ₂₆	do	-25.750	-25.949	-34.186	-39.872	-43.732	-46.610	-48.816
1-Tetradecene.....	C ₁₄ H ₂₈	do	-27.253	-27.472	-36.847	-42.901	-47.166	-50.341	-52.771
1-Pentadecene.....	C ₁₅ H ₃₀	do	-28.755	-28.994	-39.295	-45.930	-50.601	-54.072	-56.730
1-Hexadecene.....	C ₁₆ H ₃₂	do	-30.251	-30.517	-41.743	-48.959	-54.032	-57.803	-60.685
1-Heptadecene.....	C ₁₇ H ₃₄	do	-31.753	-32.039	-44.190	-51.988	-57.467	-61.534	-64.644
1-Octadecene.....	C ₁₈ H ₃₆	do	-33.256	-33.562	-46.638	-55.017	-60.902	-65.265	-68.600
1-Nonadecene.....	C ₁₉ H ₃₈	do	-34.758	-35.084	-49.086	-58.046	-64.337	-68.996	-72.555
1-Eicosene.....	C ₂₀ H ₄₀	do	-36.261	-36.607	-51.534	-61.076	-67.772	-72.727	-76.514
Δ per CH ₂			-1.5012	-1.5226	-2.4472	-3.0295	-3.4341	-3.7312	-3.9568

Compound (gas)	Formula	Temperature ^a in ° K						
		900	1,000	1,100	1,200	1,300	1,400	1,500
		Logarithm of equilibrium constant of formation, ^b log ₁₀ K _f						
1-Heptene.....	C ₇ H ₁₄	-25.764	-26.326	-26.790	-27.180	-27.514	-27.792	-28.034
1-Octene.....	C ₈ H ₁₆	-29.900	-30.606	-31.185	-31.673	-32.090	-32.437	-32.744
1-Nonene.....	C ₉ H ₁₈	-34.035	-34.885	-35.580	-36.166	-36.666	-37.083	-37.455
1-Decene.....	C ₁₀ H ₂₀	-38.171	-39.164	-39.974	-40.659	-41.240	-41.730	-42.165
1-Undecene.....	C ₁₁ H ₂₂	-42.306	-43.443	-44.367	-45.150	-45.814	-46.376	-46.876
1-Dodecene.....	C ₁₂ H ₂₄	-46.442	-47.722	-48.762	-49.643	-50.391	-51.023	-51.586
1-Tridecene.....	C ₁₃ H ₂₆	-50.577	-52.001	-53.157	-54.136	-54.967	-55.669	-56.298
1-Tetradecene.....	C ₁₄ H ₂₈	-54.710	-56.278	-57.552	-58.629	-59.544	-60.315	-61.009
1-Pentadecene.....	C ₁₅ H ₃₀	-58.845	-60.558	-61.947	-63.120	-64.117	-64.962	-65.719
1-Hexadecene.....	C ₁₆ H ₃₂	-62.981	-64.837	-66.339	-67.613	-68.691	-69.608	-70.429
1-Heptadecene.....	C ₁₇ H ₃₄	-67.116	-69.116	-70.734	-72.106	-73.267	-74.255	-75.140
1-Octadecene.....	C ₁₈ H ₃₆	-71.252	-73.395	-75.129	-76.599	-77.842	-78.901	-79.850
1-Nonadecene.....	C ₁₉ H ₃₈	-75.387	-77.674	-79.524	-81.092	-82.418	-83.546	-84.561
1-Eicosene.....	C ₂₀ H ₄₀	-79.522	-81.953	-83.919	-85.584	-86.992	-88.194	-89.271
Δ per CH ₂		-4.1352	-4.2790	-4.3944	-4.4926	-4.5752	-4.6463	-4.7106

^a See footnote "a" of table 3.^b $\log_{10} K_f$ represents the logarithm to the base 10 of the equilibrium constant of formation.

V. FREE ENERGIES AND EQUILIBRIA OF ISOMERIZATION OF THE BUTENES, PENTENES, AND HEXENES

From the values in tables 22 to 28, calculations were made of the values of the free energies and equilibrium constants for the isomerization of the butenes, pentenes, and hexenes, according to the reaction



The resulting values given in tables 30 and 31, under the following headings, for the isomerization reaction as written: $\Delta F^\circ/T$, the standard free-energy change divided by the absolute temperature; K , the equilibrium constant. In tables 32 and 33 are given values of N , the mole fraction of the given isomer present at equilibrium with its other alkene isomers. For any two isomers, the ratio of the corresponding values of K (or of N) in tables 30 to 33 give the ratio of the amounts of those two isomers present at equilibrium with one another in the gas phase at the given temperature. For the purpose of retaining the significance of their change with temperature, the values in tables 30 to 33 are written with more figures than are warranted by the absolute uncertainty.

In figures 3, 4, and 5 are plotted, as a function of the temperature, the values of $\Delta F^\circ/T$ given in tables 30 and 31 for the isomerization of the butenes, pentenes, and hexenes. These plots may be compared with corresponding plots for the butanes, pentanes, hexanes, heptanes, octanes, butynes, and pentynes [4, 5, 6]. From these charts, one may see at a glance, for any temperature in the given range and within the limits of uncertainty of the calculations, which of the isomers is thermodynamically most stable (lowest value of $\Delta F^\circ/T$) and which is the least stable (highest value of $\Delta F^\circ/T$).

In figures 6, 7, and 8 are plotted, as a function of temperature, for butenes, pentenes, and hexenes, respectively, the amounts, in mole fraction, of each of the isomers present at equilibrium with its other alkene isomers in the gas phase, as given in tables 32 and 33. The vertical width of each band gives the mole fraction for that isomer at the selected temperature. The mole fractions of the several isomers are plotted additively, so that their sum is unity at all temperatures.

Figure 9 gives a comparison of values from this report with experimental values for certain equilibria of isomerization among the unbranched butenes and pentenes: (a) *cis*-2-butene and *trans*-2-butene, from references [7, 8, 9]; (b) 1-butene = (*cis* + *trans*)-2-butene, from references [7, 8, 10]; (c) 1-pentene = (*cis* + *trans*)-2-pentene, from reference [11].

Table 34 gives a comparison of values from this report with experimental values for certain equilibria of isomerization of branched-chain pentenes and hexenes: (a) 2-methyl-1-butene, 3-methyl-1-butene, and 2-methyl-2-butene, from reference [11]; 2,3-dimethyl-1-butene, 3,3-dimethyl-1-butene, and 2,3-dimethyl-2-butene, from references [12, 13, 14].

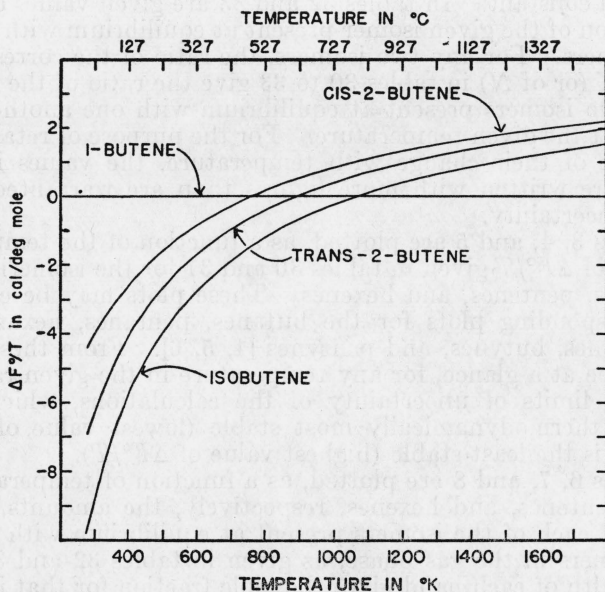


FIGURE 3.—Free energy of isomerization of the butenes.

The scale of ordinates gives the value of $\Delta F^\circ/T$, in calories per degree mole, for the isomerization of 1-butene into the other isomers, in the gaseous state, as indicated. The scale of abscissas gives the temperature in degrees Kelvin.

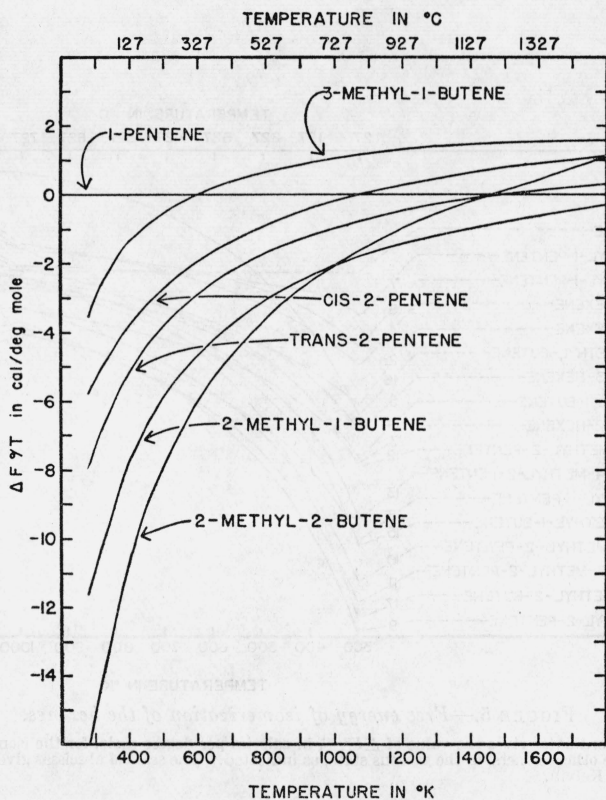


FIGURE 4.—Free energy of isomerization of the pentenes.

The scale of ordinates gives the value of $\Delta F^\circ/T$, in calories per degree mole, for the isomerization of 1-pentene into the other isomers, in the gaseous state, as indicated. The scale of abscissas gives the temperature in degrees Kelvin.

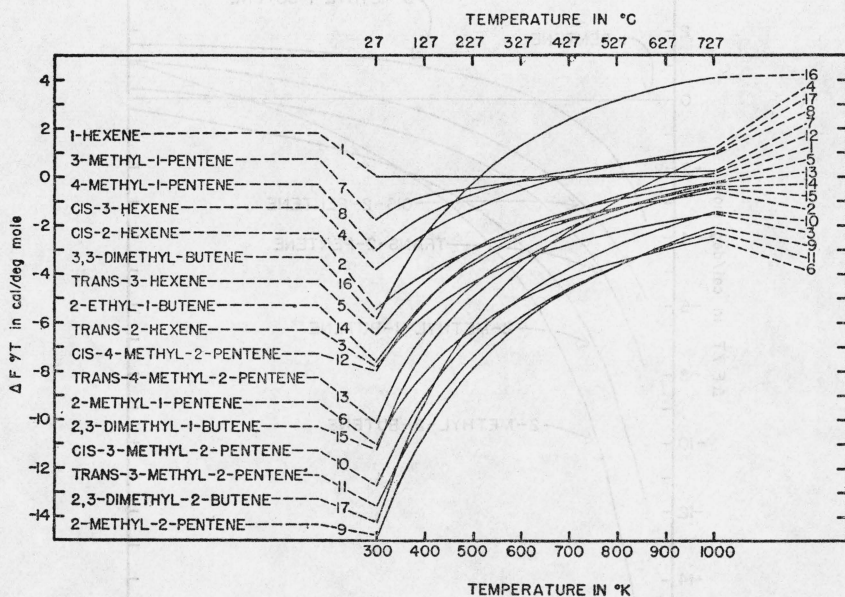


FIGURE 5.—Free energy of isomerization of the hexenes.

The scale of ordinates gives the value of $\Delta F^\circ/T$, in calories per degree mole, for the isomerization of 1-hexene into the other isomers, in the gaseous state, as indicated. The scale of abscissas gives the temperature in degrees Kelvin.

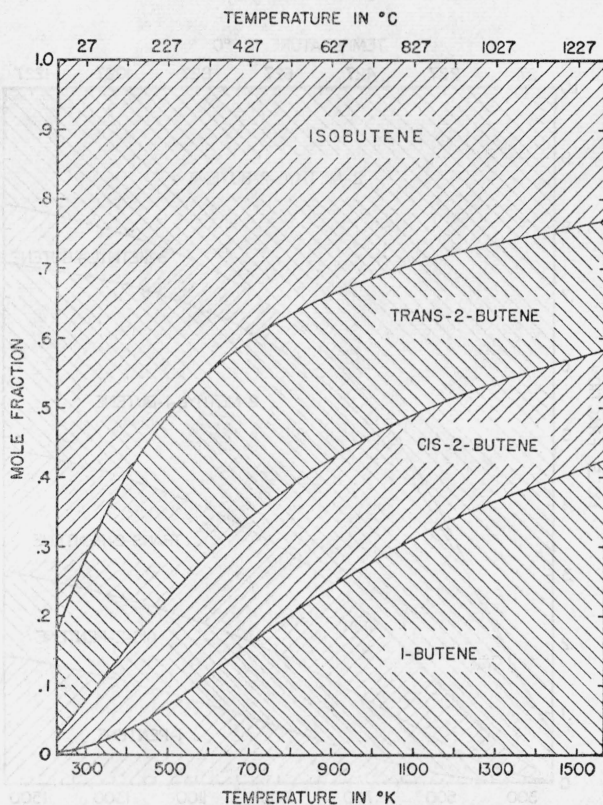


FIGURE 6.—Equilibrium concentrations of the butenes.

The scale of ordinates measures the amount in mole fraction, and the scale of abscissas gives the temperature in degrees Kelvin and degrees centigrade. The vertical width of a band at a given temperature measures the mole fraction of the given isomer present when at equilibrium with all of its other isomers, in the gas phase.

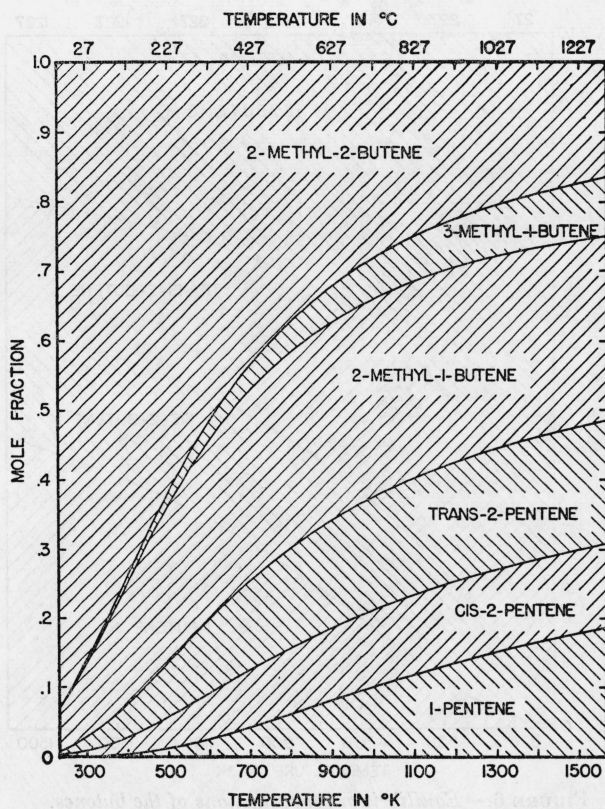


FIGURE 7.—Equilibrium concentrations of the pentenes.

The scale of ordinates measures the amount in mole fraction, and the scale of abscissas gives the temperature in degrees Kelvin and degrees centigrade. The vertical width of a band at a given temperature measures the mole fraction of the given isomer present when at equilibrium with all of its other isomers, in the gas phase.

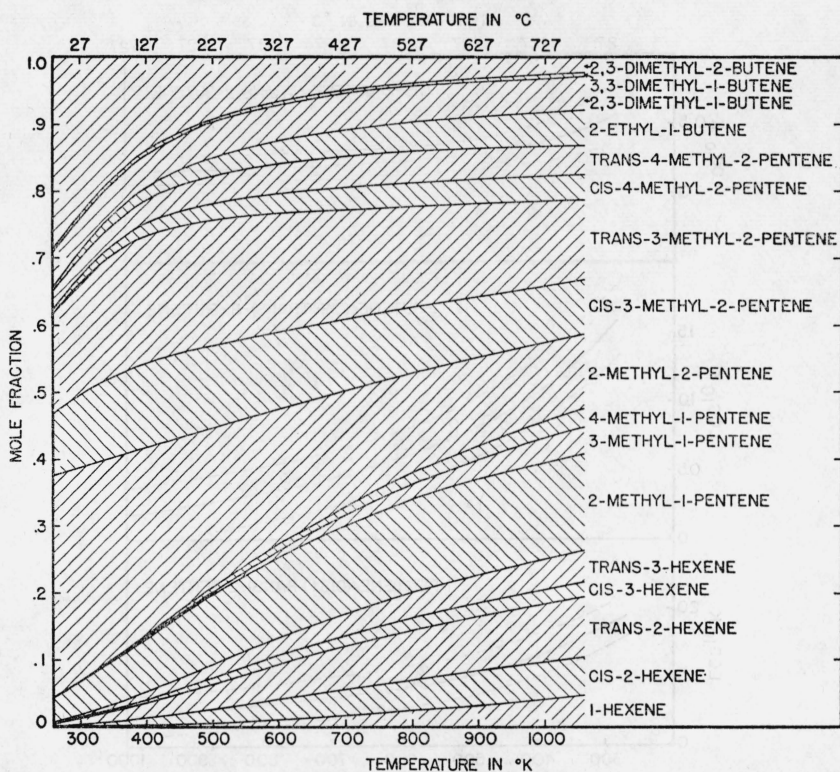


FIGURE 8.—Equilibrium concentrations of the hexenes.

The scale of ordinates measures the amount in mole fraction, and the scale of abscissas gives the temperature in degrees Kelvin and degrees centigrade. The vertical width of a band at a given temperature measures the mole fraction of the given isomer present when at equilibrium with all of its other isomers, in the gas phase.

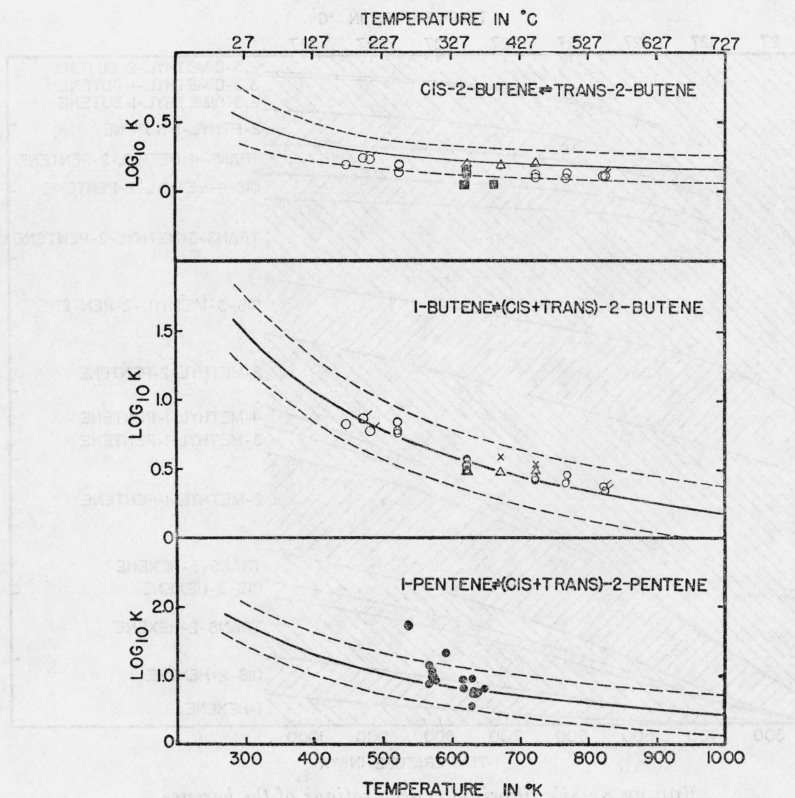


FIGURE 9.—Comparison of the calculated values of the equilibrium constant with the experimental data for several equilibria.

The scale of ordinates gives the value of the logarithm (to the base 10) of the equilibrium constant for the three given equilibria in the gaseous state. The scale of abscissas gives the temperature in degrees Kelvin.

The experimental data, represented by points, are from the following investigations:

cis-2-butene (gas) = *trans*-2-butene (gas): Frey and Huppke [7] Δ ; Shell Development Co. [8] \circ , σ ; Kistiakowsky [9] \square .

1-butene (gas) = (*cis*+*trans*)-2-butene (gas): Frey and Huppke [7] Δ ; Shell Development Co. [8] \circ , σ ; Turkevich [10] \times .

1-pentene (gas) = (*cis*+*trans*)-2-pentene (gas); Ewell and Hardy [11] \bullet .

The calculated values are given by the solid line in each case, with the estimated uncertainty given by the bordering dashed lines.

TABLE 30.—Summary of values of the free energies and equilibrium constants for the isomerization of the butenes and pentenes in the ideal gaseous state to 1,500° K

Temperature	BUTENES						PENTENES	
	1-Butene= <i>cis</i> -2-butene		1-Butene= <i>trans</i> -2-butene		1-Butene=2-methylpropene		1-Pentene= <i>cis</i> -2-pentene	
	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K
°K	cal/deg mole		cal/deg mole		cal/deg mole		cal/deg mole	
298.16	-3.93	7.21	-6.38	24.8	-8.84	85.3	-5.41	15.2
300	-3.89	7.08	-6.32	24.1	-8.76	82.0	-5.36	14.8
400	-2.43	3.40	-4.07	7.74	-5.74	17.8	-3.84	6.91
500	-1.40	2.02	-2.66	3.81	-3.90	7.12	-2.73	3.96
600	-0.647	1.38	-1.70	2.35	-2.66	3.82	-1.95	2.67
700	-.059	1.03	-0.977	1.63	-1.77	2.44	-1.38	2.00
800	+.420	0.810	-.423	1.24	-1.08	1.72	-0.886	1.56
900	+.804	.667	+.026	0.988	-0.548	1.32	-.500	1.29
1,000	+1.12	.568	+.392	.821	-.112	1.06	-.177	1.09
1,100	+1.39	.496	+.695	.705	+.248	0.883	+.072	0.964
1,200	+1.63	.440	+.956	.630	+.552	.757	+.303	.859
1,300	+1.84	.395	+1.18	.552	+.816	.663	+.469	.790
1,400	+2.03	.361	+1.37	.502	+1.04	.593	+.645	.723
1,500	+2.19	.332	+1.54	.461	+1.23	.538	+.791	.675

Temperature	PENTENES (continued)							
	1-Pentene= <i>trans</i> -2-pentene		1-Pentene=2-methyl-1-butene		1-Pentene=3-methyl-1-butene		1-Pentene=2-methyl-2-butene	
	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K
°K	cal/deg mole		cal/deg mole		cal/deg mole		cal/deg mole	
298.16	-7.42	41.8	-11.0	253	-3.06	4.66	-15.2	2060
300	-7.36	40.6	-10.9	242	-3.00	4.54	-15.1	1950
400	-5.20	13.7	-7.84	51.6	-1.36	1.98	-10.7	218
500	-3.81	6.81	-5.89	19.4	-0.559	1.33	-7.91	53.6
600	-2.89	4.28	-4.66	10.4	-.022	1.01	-6.03	20.8
700	-2.24	3.09	-3.76	6.62	+.362	0.833	-4.67	10.5
800	-1.73	2.38	-3.05	4.65	+.656	.719	-3.59	6.09
900	-1.30	1.92	-2.51	3.54	+.882	.642	-2.73	3.95
1,000	-0.961	1.62	-2.07	2.84	+1.08	.581	-2.03	2.77
1,100	-.695	1.42	-1.73	2.39	+1.21	.545	-1.47	2.10
1,200	-.484	1.28	-1.43	2.05	+1.33	.511	-0.993	1.65
1,300	-.312	1.17	-1.20	1.83	+1.40	.494	-.612	1.36
1,400	-.141	1.07	-0.973	1.63	+1.48	.476	-.244	1.13
1,500	+.023	0.989	-.785	1.48	+1.53	.464	+.069	0.97

TABLE 31.—Summary of values of the free energies and equilibrium constants for the isomerization of the hexenes in the ideal gaseous state to 1,000° K

Temperature	HEXENES											
	1-Hexene= <i>cis</i> -2-hexene		1-Hexene= <i>trans</i> -2-hexene		1-Hexene= <i>cis</i> -3-hexene		1-Hexene= <i>trans</i> -3-hexene		1-Hexene= 2-methyl-1-pentene		1-Hexene= 3-methyl-1-pentene	
	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K
° K	<i>cal/deg mole</i>		<i>cal/deg mole</i>		<i>cal/deg mole</i>		<i>cal/deg mole</i>		<i>cal/deg mole</i>		<i>cal/deg mole</i>	
298.16	-5.46	15.6	-7.87	52.5	-3.84	6.91	-6.51	26.5	-11.1	273	-1.76	2.42
300	-5.43	15.4	-7.83	51.4	-3.79	6.75	-6.46	25.8	-11.1	263	-1.73	2.39
400	-4.01	7.53	-5.67	17.4	-2.37	3.29	-4.34	8.87	-8.08	58.4	-0.793	1.49
500	-3.02	4.58	-4.34	8.90	-1.31	1.93	-2.96	4.43	-6.27	23.4	-0.453	1.26
600	-2.29	3.16	-3.42	5.59	-0.547	1.32	-2.05	2.81	-5.04	12.6	-0.176	1.09
700	-1.72	2.38	-2.75	4.00	+0.0238	0.988	-1.43	2.05	-4.14	8.03	-0.0137	1.01
800	-1.29	1.91	-2.28	3.15	+0.478	.786	-0.968	1.63	-3.49	5.79	+0.0682	0.966
900	-0.910	1.58	-1.84	2.52	+0.872	.645	-0.544	1.32	-2.96	4.43	+0.193	.908
1,000	-0.626	1.37	-1.52	2.15	+1.170	.555	-0.244	1.13	-2.54	3.59	+0.269	.874
		1-Hexene= 4-methyl-1-pentene		1-Hexene= 2-methyl-2-pentene		1-Hexene= <i>cis</i> -3-methyl-2-pentene		1-Hexene= <i>trans</i> -3-methyl-2-pentene		1-Hexene= <i>cis</i> -4-methyl-2-pentene		
		$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	
		<i>cal/deg mole</i>		<i>cal/deg mole</i>		<i>cal/deg mole</i>		<i>cal/deg mole</i>		<i>cal/deg mole</i>		
298.16	-3.03	4.60	-15.0	1,870	-12.8	634	-13.6	954	-8.05	57.4		
300	-3.00	4.52	-14.9	1,770	-12.7	605	-13.5	909	-7.97	55.2		
400	-1.57	2.21	-10.6	210	-9.03	94.0	-9.84	141	-5.11	13.1		
500	-0.725	1.44	-7.90	53.2	-6.62	28.0	-7.43	42.0	-3.47	5.74		
600	-0.134	1.07	-6.03	20.8	-4.97	12.2	-5.78	18.3	-2.31	3.20		
700	+0.235	0.888	-4.68	10.5	-3.77	6.66	-4.58	10.0	-1.46	2.08		
800	+0.485	.784	-3.63	6.22	-2.83	4.16	-3.64	6.26	-0.810	1.50		
900	+0.747	.687	-2.79	4.06	-2.08	2.84	-2.89	4.27	-0.290	1.16		
1,000	+0.918	.630	-2.11	2.89	-1.47	2.09	-2.28	3.15	+0.174	0.916		
		1-Hexene= <i>trans</i> -4-methyl-2-pentene		1-Hexene= 2-ethyl-1-butene		1-Hexene= 2,3-dimethyl-1-butene		1-Hexene= 3,3-dimethyl-1-butene		1-Hexene= 2,3-dimethyl-2-butene		
		$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	$\Delta F^\circ/T$	K	
		<i>cal/deg mole</i>		<i>cal/deg mole</i>		<i>cal/deg mole</i>		<i>cal/deg mole</i>		<i>cal/deg mole</i>		
298.16	-10.2	169	-7.69	47.9	-11.3	296	-5.91	19.6	-14.4	1,390		
300	-10.1	161	-7.62	46.2	-11.2	281	-5.82	18.7	-14.3	1,310		
400	-6.48	26.1	-5.14	13.3	-7.17	36.9	-2.40	3.35	-9.25	105		
500	-4.46	9.45	-3.58	6.06	-4.94	12.0	-0.298	1.16	-6.01	20.6		
600	-3.07	4.70	-2.54	3.60	-3.45	5.68	+1.30	0.533	-3.80	6.76		
700	-2.08	2.84	-1.79	2.46	-2.38	3.32	+2.41	.301	-2.19	3.02		
800	-1.35	1.97	-1.24	1.86	-1.60	2.24	+3.17	.203	-0.944	1.61		
900	-0.713	1.43	-0.772	1.48	-0.972	1.63	+3.71	.158	+0.088	0.957		
1,000	-0.221	1.12	-0.426	1.24	-0.461	1.26	+4.07	.128	+0.913	.632		

TABLE 32.—Values of the equilibrium concentrations for the isomerization of the butenes and pentenes in the ideal gaseous state to 1500° K

Temperature	Composition, in mole fraction, of equilibrium mixture of isomers			
	BUTENES			
	1-Butene	cis-2-Butene	trans-2-Butene	2-Methylpropene
°K				
298.16	0.0084	0.0609	0.210	0.721
300	.0088	.0620	.211	.718
400	.0334	.114	.259	.595
500	.0717	.145	.273	.510
600	.117	.161	.275	.447
700	.164	.169	.267	.400
800	.210	.170	.260	.360
900	.252	.168	.249	.332
1,000	.290	.165	.238	.305
1,100	.324	.161	.229	.286
1,200	.354	.156	.223	.268
1,300	.383	.151	.211	.254
1,400	.414	.149	.191	.246
1,500	.429	.142	.198	.231

	PENTENES					
	1-Pentene	cis-2-Pentene	trans-2-Pentene	2-Methyl-1-butene	3-Methyl-1-butene	2-Methyl-2-butene
298.16	0.0004	0.0064	0.0176	0.107	0.0020	0.867
300	.0004	.0066	.0180	.107	.0020	.866
400	.0034	.0236	.0468	.176	.0068	.744
500	.0116	.0459	.0789	.227	.0154	.621
600	.0249	.0666	.107	.260	.0252	.517
700	.0416	.0834	.129	.276	.0347	.436
800	.0610	.0952	.145	.283	.0438	.371
900	.0811	.104	.156	.287	.0520	.320
1,000	.101	.110	.164	.286	.0587	.280
1,100	.119	.115	.169	.284	.0648	.249
1,200	.136	.117	.174	.279	.0696	.224
1,300	.151	.119	.176	.275	.0744	.205
1,400	.166	.120	.178	.270	.0788	.187
1,500	.179	.121	.177	.266	.0831	.173

TABLE 33.—*Values of the equilibrium concentrations for the isomerization of the hexenes in the ideal gaseous state to 1,000° K*

Temperature	Composition, in mole fraction, of equilibrium mixture of isomers					
	HEXENES					
	1-Hexene	cis-2-Hexene	trans-2-Hexene	cis-3-Hexene	trans-3-Hexene	2-Methyl-1-pentene
° K						
298.16	0.000172	0.00269	0.00903	0.00119	0.00456	0.0469
300	.000181	.00278	.00931	.00122	.00468	.0477
400	.00135	.0101	.0234	.00443	.0119	.0755
500	.00444	.0203	.0395	.00858	.0197	.104
600	.00957	.0302	.0535	.0126	.0269	.121
700	.0162	.0386	.0649	.0161	.0333	.130
800	.0238	.0455	.0749	.0187	.0388	.138
900	.0322	.0509	.0812	.0208	.0423	.142
1,000	.0404	.0554	.0869	.0224	.0457	.145
	3-Methyl-1-pentene	4-Methyl-1-pentene	2-Methyl-2-pentene	cis-3-Methyl-2-pentene	trans-3-Methyl-2-pentene	cis-4-Methyl-2-pentene
298.16	0.000416	0.000791	0.321	0.109	0.164	0.00987
300	.000433	.000819	.320	.110	.165	.0100
400	.00201	.00297	.283	.126	.190	.0176
500	.00558	.00639	.236	.124	.187	.0255
600	.0105	.0102	.200	.117	.175	.0306
700	.0164	.0144	.171	.108	.163	.0339
800	.0230	.0187	.148	.099	.149	.0358
900	.0292	.0221	.131	.091	.138	.0372
1,000	.0353	.0255	.117	.085	.127	.0370
	trans-4-Methyl-2-pentene	2-Ethyl-1-butene	2,3-Dimethyl-1-butene	3,3-Dimethyl-1-butene	2,3-Dimethyl-2-butene	
298.16	0.0291	0.00824	0.0509	0.00336	0.239	
300	.0292	.00837	.0509	.00339	.237	
400	.0351	.0179	.0500	.00451	.141	
500	.0419	.0269	.0534	.00516	.0916	
600	.0450	.0344	.0544	.00511	.0648	
700	.0462	.0400	.0539	.00490	.0490	
800	.0469	.0444	.0534	.00483	.0383	
900	.0461	.0475	.0525	.00509	.0308	
1,000	.0452	.0501	.0510	.00519	.0255	

TABLE 34.—Comparison of values from this report with experimental values for certain equilibria of isomerization of branched-chain pentenes and hexenes

PENTENES				
Source	Temperature	3-Methyl-1-butene	2-Methyl-1-butene	2-Methyl-2-butene
	°K	Mole fraction at equilibrium		
Experimental [11]-----	631	0.034	0.273	0.693
Calculated (this report)-----	631	.036	.339	.625
HEXENES				
Source	Temperature	2,3-Dimethyl-1-butene	3,3-Dimethyl-1-butene	2,3-Dimethyl-2-butene
	°K	Mole fraction at equilibrium		
Experimental [12]-----	573	0.332	0.034	0.634
Experimental [13]-----	548	.337	.038	.625
Experimental [14]-----	558	.28	.07	.65
Calculated (this report)-----	545	.395	.038	.567
	575	.419	.040	.541

VI. EQUILIBRIUM CONSTANTS FOR SOME REACTIONS INVOLVING HYDROGENATION, DIMERIZATION, AND ALKYLATION

In figure 10 are plotted, as a function of temperature, values of the logarithm of the equilibrium constant for the reaction of hydrogenation of a given normal 1-alkene to the corresponding normal paraffin [5]. The curves show the change in the value of the logarithm of the equilibrium constant of hydrogenation with increase in number of carbon atoms in the molecule. Table 35 gives the numerical values of the equilibrium constant, and of its logarithm, for these reactions of hydrogenation. Table 36 gives a comparison of values from this report with experimental values for certain equilibria of hydrogenation from reference [7, 15].

Table 37 presents numerical values of the equilibrium constant, and of its logarithm, for some reactions of dimerization. In figure 11 are plotted, as a function of temperature, values of the logarithm of the equilibrium constant for these reactions of dimerization. The effect of changing isomers, either reactants or products, can be determined readily from tables 30 and 31.

Table 38 presents numerical values of the equilibrium constant, and of its logarithm, for some reactions of alkylation, which is the addition of a paraffin to a monoolefin molecule. The value for 2,2,5-trimethylhexane used in these calculations is a preliminary one obtained by adding to the value for 2,2,4-trimethylpentane [5], the appropriate difference between the values for 2,4-dimethylpentane and 2,5-dimethylhexane from [5, 16]. In figure 12 are plotted, as a function of temperature, values of the logarithm of the equilibrium constant for these reactions of alkylation. The effect of changing isomers, either reactants or products, can be determined readily from tables 30 and 31 of this report and the tables in references [5, 16].

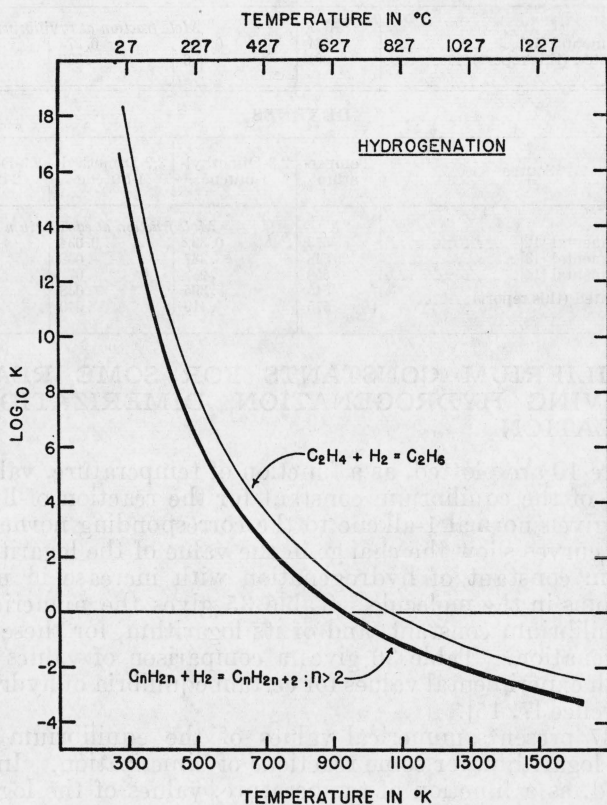


FIGURE 10.—Logarithm of the equilibrium constant for the reaction of hydrogenation of 1-alkenes to *n*-paraffins.

The scale of ordinates gives the value of the logarithm (to the base 10) of the equilibrium constant for the reaction of hydrogenation of a given 1-alkene to the corresponding normal paraffin, in the gaseous state. The scale of abscissas gives the temperature in degrees Kelvin. The values calculated for propylene, 1-butene, and the higher 1-alkenes all fall within the width of the heavy line indicated. The corresponding numerical values are given in table 35.

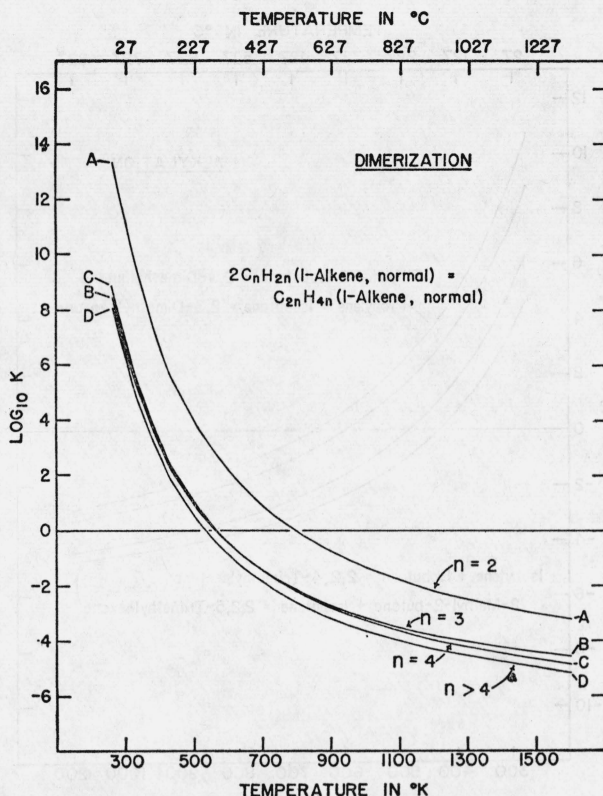


FIGURE 11.—*Logarithm of the equilibrium constant for some reactions of dimerization.*

The scale of ordinates gives the value of the logarithm (to the base 10) of the equilibrium constant for some reactions of dimerization of 1-alkenes to 1-alkenes, in the gaseous state. The scale of abscissas gives the temperature in degrees Kelvin. The lowest curve shown is that for 1-pentene and higher 1-alkenes. The corresponding numerical values are given in table 37.

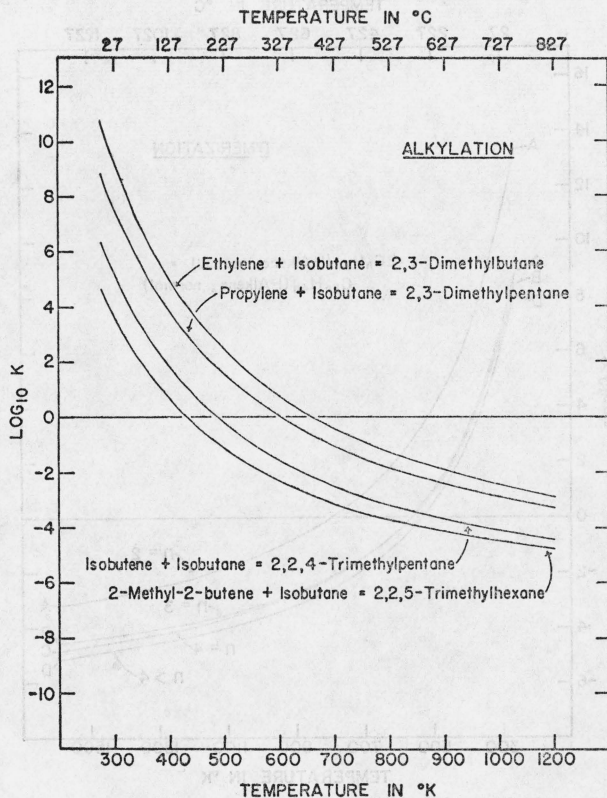


FIGURE 12.—*Logarithm of the equilibrium constant for some reactions of alkylation.*

The scale of ordinates gives the value of the logarithm (to the base 10) of the equilibrium constant for some reactions of alkylation (addition of an olefin to a paraffin to form a paraffin), in the gaseous state. The scale of abscissas gives the temperature in degrees Kelvin. The corresponding numerical values are given in table 38.

TABLE 35.—*Equilibrium constant, and its logarithm, for the reaction of hydrogenation of 1-alkenes to n-paraffins*

Reaction	Temperature in °K						
	298.16	300	400	500	600	700	800
	Logarithm of the equilibrium constant, log ₁₀ K						
1-Alkene (gas) + H ₂ (gas) = n-paraffin (gas)							
C ₂ H ₄ (gas) + H ₂ (gas) = C ₂ H ₆ (gas)	17.6958	17.5494	11.5404	7.9014	5.4444	3.6778	2.3423
C ₃ H ₆ (gas) + H ₂ (gas) = C ₃ H ₈ (gas)	15.1025	15.0014	9.5170	6.2154	3.9906	2.3935	1.1911
C ₄ H ₈ (gas) + H ₂ (gas) = C ₄ H ₁₀ (gas)	15.3715	15.2364	9.7090	6.3650	4.1017	2.4706	1.2443
C ₅ H ₁₀ (gas) + H ₂ (gas) = C ₅ H ₁₂ (gas)	15.2070	15.0725	9.5615	6.2095	3.9550	2.3313	1.1050
C ₆ H ₁₂ (gas) + H ₂ (gas) = C ₆ H ₁₄ (gas)	15.2121	15.0748	9.5646	6.2247	3.9683	2.3428	1.1243
C _n H _{2n} (gas) + H ₂ (gas) = C _n H _{2n+2} (gas); n > 6	15.2090	15.0773	9.5649	6.2228	3.9669	2.3402	1.1210

Reaction	Temperature in °K						
	900	1,000	1,100	1,200	1,300	1,400	1,500
	Logarithm of the equilibrium constant, log ₁₀ K						
1-Alkene (gas) + H ₂ (gas) = n-paraffin (gas)							
C ₂ H ₄ (gas) + H ₂ (gas) = C ₂ H ₆ (gas)	1.2992	0.4634	-0.2229	-0.7937	-1.2766	-1.6897	-2.0495
C ₃ H ₆ (gas) + H ₂ (gas) = C ₃ H ₈ (gas)	0.2547	-.4930	-1.1044	-1.6136	-2.0430	-2.4116	-2.7382
C ₄ H ₈ (gas) + H ₂ (gas) = C ₄ H ₁₀ (gas) .....	.2890	-.4758	-1.1039	-1.6302	-2.0772	-2.4581	-2.7908
C ₅ H ₁₀ (gas) + H ₂ (gas) = C ₅ H ₁₂ (gas) .....	.1492	-.6177	-1.2431	-1.7653	-2.2042	-2.5838	-2.9200
C ₆ H ₁₂ (gas) + H ₂ (gas) = C ₆ H ₁₄ (gas) .....	.1639	-.6017	-1.2271	-1.7490	-2.1890	-2.5712	-2.9090
C _n H _{2n} (gas) + H ₂ (gas) = C _n H _{2n+2} (gas); n > 6 .....	.1635	-.6008	-1.2284	-1.7475	-2.1889	-2.5706	-2.9101

TABLE 35.—Equilibrium constant, and its logarithm, for the reaction of hydrogenation of 1-alkenes to *n*-paraffins—Continued

Reaction	Temperature in °K						
	298.16	300	400	500	600	700	800
	Equilibrium constant, <i>K</i>						
1-Alkene (gas) + H ₂ (gas) = <i>n</i> -paraffin (gas)							
C ₂ H ₄ (gas) + H ₂ (gas) = C ₂ H ₆ (gas).....	4.97 x 10 ¹⁷	3.54 x 10 ¹⁷	3.47 x 10 ¹¹	7.96 x 10 ⁷	2.78 x 10 ⁵	4.76 x 10 ³	2.20 x 10 ²
C ₃ H ₆ (gas) + H ₂ (gas) = C ₃ H ₈ (gas).....	1.27 x 10 ¹⁵	1.00 x 10 ¹⁵	3.29 x 10 ⁹	1.64 x 10 ⁶	9.78 x 10 ³	2.47 x 10 ²	1.55 x 10 ¹
C ₄ H ₈ (gas) + H ₂ (gas) = C ₄ H ₁₀ (gas).....	2.35 x 10 ¹⁵	1.72 x 10 ¹⁵	5.12 x 10 ⁹	2.32 x 10 ⁶	1.26 x 10 ⁴	2.95 x 10 ²	1.75 x 10 ¹
C ₅ H ₁₀ (gas) + H ₂ (gas) = C ₅ H ₁₂ (gas).....	1.61 x 10 ¹⁵	1.18 x 10 ¹⁵	3.64 x 10 ⁹	1.62 x 10 ⁶	9.02 x 10 ³	2.14 x 10 ²	1.27 x 10 ¹
C ₆ H ₁₂ (gas) + H ₂ (gas) = C ₆ H ₁₄ (gas).....	1.63 x 10 ¹⁵	1.19 x 10 ¹⁵	3.67 x 10 ⁹	1.68 x 10 ⁶	9.29 x 10 ³	2.20 x 10 ²	1.33 x 10 ¹
C _{<i>n</i>} H _{2<i>n</i>} (gas) + H ₂ (gas) = C _{<i>n</i>} H _{2<i>n</i>+2} (gas); <i>n</i> > 6.....	1.63 x 10 ¹⁵	1.19 x 10 ¹⁵	3.67 x 10 ⁹	1.67 x 10 ⁶	9.27 x 10 ³	2.19 x 10 ²	1.32 x 10 ¹

Reaction	Temperature in °K						
	900	1,000	1,100	1,200	1,300	1,400	1,500
	Equilibrium constant, <i>K</i>						
1-Alkene (gas) + H ₂ (gas) = <i>n</i> -paraffin (gas)							
C ₂ H ₄ (gas) + H ₂ (gas) = C ₂ H ₆ (gas).....	19.9	2.90	5.98 x 10 ⁻¹	1.61 x 10 ⁻¹	5.28 x 10 ⁻²	2.04 x 10 ⁻²	8.91 x 10 ⁻³
C ₃ H ₆ (gas) + H ₂ (gas) = C ₃ H ₈ (gas).....	1.80	.321	7.86 x 10 ⁻²	2.44 x 10 ⁻²	9.06 x 10 ⁻³	3.88 x 10 ⁻³	1.83 x 10 ⁻³
C ₄ H ₈ (gas) + H ₂ (gas) = C ₄ H ₁₀ (gas).....	1.95	.334	7.87 x 10 ⁻²	2.34 x 10 ⁻²	8.37 x 10 ⁻³	3.48 x 10 ⁻³	1.62 x 10 ⁻³
C ₅ H ₁₀ (gas) + H ₂ (gas) = C ₅ H ₁₂ (gas).....	1.41	.241	5.72 x 10 ⁻²	1.72 x 10 ⁻²	6.25 x 10 ⁻³	2.61 x 10 ⁻³	1.51 x 10 ⁻³
C ₆ H ₁₂ (gas) + H ₂ (gas) = C ₆ H ₁₄ (gas).....	1.46	.250	5.93 x 10 ⁻²	1.78 x 10 ⁻²	6.47 x 10 ⁻³	2.69 x 10 ⁻³	1.23 x 10 ⁻³
C _{<i>n</i>} H _{2<i>n</i>} (gas) + H ₂ (gas) = C _{<i>n</i>} H _{2<i>n</i>+2} (gas); <i>n</i> > 6.....	1.46	.251	5.91 x 10 ⁻²	1.79 x 10 ⁻²	6.47 x 10 ⁻³	2.69 x 10 ⁻³	1.23 x 10 ⁻³

TABLE 36.—Comparison of values from this report with experimental values for certain equilibria of hydrogenation

Reaction (gas phase)	Temperature ° K	Logarithm of equilibrium constant, $\log_{10} K$		
		Experimental	Calculated	Difference
Frey and Huppke [7]				
$C_2H_4+H_2=C_2H_6$	$\left\{ \begin{array}{l} 673 \\ 723 \\ 773 \end{array} \right.$	$\left\{ \begin{array}{l} 3.824 \\ 3.119 \\ 2.495 \end{array} \right.$	$\left\{ \begin{array}{l} 4.112 \\ 3.342 \\ 2.660 \end{array} \right.$	$\left\{ \begin{array}{l} 0.288 \\ .223 \\ .165 \end{array} \right.$
$C_3H_6+H_2=C_3H_8$	$\left\{ \begin{array}{l} 623 \\ 673 \\ 723 \end{array} \right.$	$\left\{ \begin{array}{l} 3.420 \\ 2.658 \\ 2.131 \end{array} \right.$	$\left\{ \begin{array}{l} 3.577 \\ 2.780 \\ 2.087 \end{array} \right.$	$\left\{ \begin{array}{l} .157 \\ .122 \\ -.044 \end{array} \right.$
$1-C_4H_8+H_2=n-C_4H_{10}$	$\left\{ \begin{array}{l} 623 \\ 673 \\ 723 \end{array} \right.$	$\left\{ \begin{array}{l} 3.347 \\ 2.658 \\ 2.125 \end{array} \right.$	$\left\{ \begin{array}{l} 3.691 \\ 2.871 \\ 2.153 \end{array} \right.$	$\left\{ \begin{array}{l} .344 \\ .213 \\ .028 \end{array} \right.$
<i>trans</i> - $C_4H_8+H_2=n-C_4H_{10}$	$\left\{ \begin{array}{l} 623 \\ 673 \\ 723 \end{array} \right.$	$\left\{ \begin{array}{l} 3.081 \\ 2.409 \\ 1.854 \end{array} \right.$	$\left\{ \begin{array}{l} 3.348 \\ 2.613 \\ 1.975 \end{array} \right.$	$\left\{ \begin{array}{l} .267 \\ .204 \\ .121 \end{array} \right.$
<i>cis</i> - $C_4H_8+H_2=n-C_4H_{10}$	$\left\{ \begin{array}{l} 623 \\ 723 \\ 723 \end{array} \right.$	$\left\{ \begin{array}{l} 3.284 \\ 2.602 \\ 2.060 \end{array} \right.$	$\left\{ \begin{array}{l} 3.569 \\ 2.819 \\ 2.170 \end{array} \right.$	$\left\{ \begin{array}{l} .285 \\ .217 \\ .110 \end{array} \right.$
<i>iso</i> - $C_4H_8+H_2=iso-C_4H_{10}$	$\left\{ \begin{array}{l} 623 \\ 673 \\ 723 \end{array} \right.$	$\left\{ \begin{array}{l} 2.770 \\ 2.000 \\ 1.377 \end{array} \right.$	$\left\{ \begin{array}{l} 2.911 \\ 2.154 \\ 1.496 \end{array} \right.$	$\left\{ \begin{array}{l} .141 \\ .154 \\ .119 \end{array} \right.$
Kistiakowsky [15]				
$C_2H_4+H_2=C_2H_6$	$\left\{ \begin{array}{l} 723 \\ 653 \end{array} \right.$	$\left\{ \begin{array}{l} 3.287 \\ 4.394 \end{array} \right.$	$\left\{ \begin{array}{l} 3.342 \\ 4.439 \end{array} \right.$	$\left\{ \begin{array}{l} 0.055 \\ .045 \end{array} \right.$
$C_3H_6+H_2=C_3H_8$	$\left\{ \begin{array}{l} 648 \\ 583 \end{array} \right.$	$\left\{ \begin{array}{l} 3.280 \\ 4.434 \end{array} \right.$	$\left\{ \begin{array}{l} 3.160 \\ 4.319 \end{array} \right.$	$\left\{ \begin{array}{l} -.120 \\ -.115 \end{array} \right.$

TABLE 37—Equilibrium constant, and its logarithm, for the reaction of dimerization of normal 1-alkenes to normal 1-alkenes

Reaction	Temperature in °K						
	298.16	300	400	500	600	700	800
	Logarithm of the equilibrium constant, log ₁₀ K						
2 C ₂ H ₄ (ethylene, gas) = C ₄ H ₈ (1-butene, gas)	11.249	11.139	6.636	3.960	2.180	0.919	-0.020
2 C ₃ H ₆ (propylene, gas) = C ₆ H ₁₂ (1-hexene, gas)	6.650	6.559	2.976	0.857	-0.546	-1.534	-2.268
2 C ₄ H ₈ (1-butene, gas) = C ₈ H ₁₆ (1-octene, gas)	6.996	6.899	3.191	1.005	-1.445	-1.472	-2.230
2 C ₅ H ₁₀ (1-pentene, gas) = C ₁₀ H ₂₀ (1-decene, gas)	6.291	6.200	2.617	0.495	-1.905	-1.891	-2.625
2 C _n H _{2n} (1-alkene, normal, gas) = C _{2n} H _{4n} (1-alkene, normal, gas); n > 5 ..	6.251	6.161	2.590	.491	-1.904	-1.892	-2.611

Reaction	Temperature in °K						
	900	1,000	1,100	1,200	1,300	1,400	1,500
	Logarithm of the equilibrium constant, log ₁₀ K						
2 C ₂ H ₄ (ethylene, gas) = C ₄ H ₈ (1-butene, gas)	-0.745	-1.319	-1.787	-2.172	-2.495	-2.768	-3.004
2 C ₃ H ₆ (propylene, gas) = C ₆ H ₁₂ (1-hexene, gas)	-2.822	-3.263	-3.619	-3.922	-4.176	-4.387	-4.564
2 C ₄ H ₈ (1-butene, gas) = C ₈ H ₁₆ (1-octene, gas)	-2.811	-3.272	-3.643	-3.954	-4.218	-4.440	-4.637
2 C ₅ H ₁₀ (1-pentene, gas) = C ₁₀ H ₂₀ (1-decene, gas)	-3.191	-3.639	-3.992	-4.287	-4.529	-4.746	-4.951
2 C _n H _{2n} (1-alkene, normal, gas) = C _{2n} H _{4n} (1-alkene, normal, gas); n > 5 ..	-3.182	-3.626	-3.970	-4.263	-4.509	-4.730	-4.940

Reaction	Temperature in °K						
	298.16	300	400	500	600	700	800
	Equilibrium constant, K						
2 C ₂ H ₄ (ethylene, gas) = C ₄ H ₈ (1-butene, gas)	1.77×10 ¹¹	1.38×10 ¹¹	4.33×10 ⁶	9.12×10 ³	1.51×10 ²	8.30	0.955
2 C ₃ H ₆ (propylene, gas) = C ₆ H ₁₂ (1-hexene, gas)	4.46×10 ⁶	3.62×10 ⁶	9.46×10 ²	7.19	0.284	2.92×10 ⁻²	5.40×10 ⁻³
2 C ₄ H ₈ (1-butene, gas) = C ₈ H ₁₆ (1-octene, gas)	9.91×10 ⁶	7.93×10 ⁶	1.55×10 ³	10.1	.359	3.37×10 ⁻²	5.89×10 ⁻³
2 C ₅ H ₁₀ (1-pentene, gas) = C ₁₀ H ₂₀ (1-decene, gas)	1.95×10 ⁶	1.59×10 ⁶	4.14×10 ²	3.13	.125	1.29×10 ⁻²	2.37×10 ⁻³
2 C _n H _{2n} (1-alkene, normal, gas) = C _{2n} H _{4n} (1-alkene, normal, gas); n > 5 ..	1.78×10 ⁶	1.45×10 ⁶	3.90×10 ²	3.10	.125	1.28×10 ⁻²	2.45×10 ⁻³

Reaction	Temperature in °K						
	900	1,000	1,100	1,200	1,300	1,400	1,500
	Equilibrium constant, K						
2 C ₂ H ₄ (ethylene, gas) = C ₄ H ₈ (1-butene, gas)	0.180	4.80×10 ⁻²	1.63×10 ⁻²	6.73×10 ⁻³	3.20×10 ⁻³	1.71×10 ⁻³	9.91×10 ⁻⁴
2 C ₃ H ₆ (propylene, gas) = C ₆ H ₁₂ (1-hexene, gas)	1.51×10 ⁻³	5.64×10 ⁻⁴	2.40×10 ⁻⁴	1.20×10 ⁻⁴	6.67×10 ⁻⁵	4.10×10 ⁻⁵	2.73×10 ⁻⁵
2 C ₄ H ₈ (1-butene, gas) = C ₈ H ₁₆ (1-octene, gas)	1.55×10 ⁻⁴	5.35×10 ⁻⁵	2.28×10 ⁻⁵	1.11×10 ⁻⁵	6.05×10 ⁻⁶	3.63×10 ⁻⁶	2.31×10 ⁻⁶
2 C ₅ H ₁₀ (1-pentene, gas) = C ₁₀ H ₂₀ (1-decene, gas)	6.44×10 ⁻⁴	2.30×10 ⁻⁴	1.02×10 ⁻⁴	5.16×10 ⁻⁵	2.96×10 ⁻⁵	1.80×10 ⁻⁵	1.12×10 ⁻⁵
2 C _n H _{2n} (1-alkene, normal, gas) = C _{2n} H _{4n} (1-alkene, normal, gas); n > 5 ..	6.58×10 ⁻⁴	2.37×10 ⁻⁴	1.07×10 ⁻⁴	5.46×10 ⁻⁵	3.10×10 ⁻⁵	1.86×10 ⁻⁵	1.15×10 ⁻⁵

TABLE 38.—*Equilibrium constant, and its logarithm, for some reactions of alkylation (addition of olefin to paraffin)*

Reaction	Temperature in ° K								
	298.16	300	400	500	600	700	800	900	1,000
Monoolefin (gas)+isobutane (gas)=isoparaffin (gas)	Logarithm of the equilibrium constant, $\log_{10} K$								
Ethylene (gas)+isobutane (gas)=2,3-dimethylbutane (gas)	9.321	9.214	4.993	2.475	0.793	-0.393	-1.264	-1.925	-2.434
Propylene (gas)+isobutane (gas)=2,3-dimethylpentane (gas)	7.684	7.592	3.810	1.538	0.014	-1.072	-1.869	-2.469	-2.926
Isobutene (gas)+isobutane (gas)=2,2,4-trimethylpentane (gas)	5.240	5.156	1.807	-0.210	-1.560	-2.507	-3.177	-3.678	-4.073
2-Methyl-2-butene (gas)+isobutane (gas)=2,2,5-trimethylhexane (gas)	3.710	3.633	0.647	-1.128	-2.313	-3.134	-3.700	-4.120	-4.458
	Equilibrium constant, K								
Ethylene (gas)+isobutane (gas)=2,3-dimethylbutane (gas)	2.09×10^9	1.64×10^9	9.84×10^4	2.99×10^3	6.21	0.405	5.45×10^{-2}	1.19×10^{-3}	3.68×10^{-5}
Propylene (gas)+isobutane (gas)=2,3-dimethylpentane (gas)	4.83×10^7	3.90×10^8	6.46×10^3	34.5	1.03	8.46×10^{-2}	1.36×10^{-3}	3.40×10^{-5}	1.19×10^{-5}
Isobutene (gas)+isobutane (gas)=2,2,4-trimethylpentane (gas)	1.74×10^5	1.43×10^5	64.1	0.617	2.75×10^{-2}	3.14×10^{-3}	6.65×10^{-4}	2.10×10^{-4}	8.45×10^{-5}
2-Methyl-2-butene (gas)+isobutane (gas)=2,2,5-trimethylhexane (gas)	5.13×10^3	4.30×10^3	4.44	7.45×10^{-2}	4.86×10^{-3}	7.35×10^{-4}	2.00×10^{-4}	7.59×10^{-5}	3.48×10^{-5}

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